WL-TR-96- 3076

INTEGRATED MISSION/PRECISION ATTACK COCKPIT TECHNOLOGY (IMPACT)

PHASE II: CUEING BENEFITS OF LARGE TACTICAL SITUATION DISPLAYS, HELMET-MOUNTED DISPLAYS, AND DIRECTIONAL AUDIO

G. SCOTT BOUCEK
HORACE A. ORR
ROBERT D. WILLIAMS
ANTHONY J. MONTECALVO
MARK C. REDDEN
EVAN P. ROLEK
SCOTT M. CONE

VEDA INCORPORATED
5200 SPRINGFIELD PIKE, SUITE 200
DAYTON, OH 45431-1255

GREGORY J. BARBATO
WL/FIGP

APRIL 1996
FINAL REPORT FOR 05/01/94-12/31/95

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.

FLIGHT DYNAMICS DIRECTORATE
WRIGHT LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT PATTERSON AFB OH 45433-7562

NOTICE

When government drawings, specifications, or other data are used for any purpose other than in connection with a definitely government-related procurement, the United States Government incurs no responsibility nor any obligation whatsoever. The fact the government may have formulated, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise in any manner construed, as licensing the holder or any other person or corporation, or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

RICHARD W. MOSS
CHIEF, COCKPIT DEVELOPMENT SECTION
ADVANCED COCKPITS BRANCH
FLIGHT CONTROL DIVISION

DR. JOHN M. REISING
ADVANCED COCKPITS TTIPT LEADER
FLIGHT DYNAMICS DIRECTORATE
WRIGHT LABORATORY

MICHAEL J. LYSAGHT, MAJOR, USAF
CHIEF, ADVANCED COCKPITS BRANCH
FLIGHT CONTROL DIVISION
FLIGHT DYNAMICS DIRECTORATE

DAVID P. LEMASTER
CHIEF, FLIGHT CONTROL DIVISION
FLIGHT DYNAMICS DIRECTORATE
WRIGHT LABORATORY

If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization, please notify Wright Laboratory; Flight Dynamics Directorate; WL/FIGP, Bldg 146, 2210 Eighth Street, Ste 11; Wright-Patterson Air Force Base OH 45433-7521 USA

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE APR 1996	3. REPORT TYPE AND DATES COVERED FINAL (5/94 -- 12/95)

4. TITLE AND SUBTITLE
Integrated Mission Precision Attack Cockpit Technology (IMPACT)
Phase II: Cueing Benefits Of Large Tactical Situation Displays, Helmet-Mounted Displays, and Directional Audio

5. FUNDING NUMBERS
C F33615-93-D-3800
PE: 62201F
PR: 2403
TA: 04
WU: SP

6. AUTHOR(S)
G. Scott Boucek, Horace A. Orr, Robert D. Williams, Anthony J. Montecalvo
Mark C. Redden, Evan P. Rolek, Scott M. Cone

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Veda, Incorporated
5200 Springfield Pike, Suite 200
Dayton, OH 45431-1255

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Flight Dynamics Directorate
Wright Laboratory
Air Materiel Command
Wright-Patterson AFB OH 45433-7562

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
WL-TR-96- 3076

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION IS UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

The Wright Laboratory has initiated a program called the Integrated Mission/Precision Attack Cockpit Technology (IMPACT) program, whose purpose is to determine cockpit and Pilot-Vehicle Interface (PVI) requirements for a single-seat, multi-role fighter aircraft performing at night and in adverse weather. A structured systems engineering process is being utilized to focus on the conceptual phase of cockpit development. In support of this, Veda has employed a building block approach consisting of a literature review, design work, mission/human factors analysis, and pilot-in-the-loop simulation. The focus of this evaluation was on the integration of Helmet-Mounted Displays (HMD), Large Tactical Situation Displays (TSD), and Directional Audio to aid the pilot in threat and target acquisition (functions that are currently supported by a second crewmember). In order to understand the effects of integrating such technologies in a fighter aircraft cockpit, the F-15E weapon system was used as a baseline for comparison. A portion of a full mission simulation was developed and executed, and required a single pilot to fly an air interdiction mission using both the baseline cockpit and the advanced IMPACT cockpit. Results indicated a significant improvement in threat acquisition time and threat acquisition success rate, and a slight improvement in target acquisition, with the IMPACT cockpit.

14. SUBJECT TERMS
Pilot Vehicle Interface, Pilot-in-the-Loop Simulation, Helmet-Mounted Displays, Large Tactical Situation Displays, Directional Audio

15. NUMBER OF PAGES 160

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ACRONYMS

ACRONYM	DEFINITION
A/A	Air-to-Air
ADI	Attitude Director Indicator
A/G	Air-to-Ground
AGL	Above Ground Level
AGM	Air-to-Ground Missile
AI	Air Interdiction
ALCS	Auditory Localization Cue Synthesizer
ANOVA	Analysis of Variance
AOA	Angle-of-Attack
CM	CounterMeasures
CRT	Cathode Ray Tubes
CSIL	Crew System Integration Laboratory
DMA	Defense Mapping Agency
DTED	Digital Terrain Elevation Data
ECM	Electronic CounterMeasures
EP	Emergency Procedure
FF	Fuel Flow
FLIR	Forward Looking Infra-Red
FOV	Field-of-View
HDD	Heads Down Display
HMD	Helmet-Mounted Display
HOTAS	Hands On Throttle and Stick
HSI	Horizontal Situation Indicator
HUD	Heads-Up Display
HYD	Hydraulic
IFR	Instrument Flight Rules
IMPACT	Integrated Mission/Precision Attack Cockpit Technology
LANTIRN	Low Altitude Navigation and Targeting Infra-Red for Night
MCS	Manned Combat Station

MFD	Multi-Function Display
MOE	Measure of Effectiveness
MOP	Measure of Performance
MOW	Measures of Workload
MSL	Mean Sea Level
MPD	Multi-Purpose Display
NAV	Navigation
NOZ	Nozzle Position
PACS	Programmable Armament Control Set
PB	Pushbutton
PVI	Pilot-Vehicle Interface
RDY	Ready
RMS	Root Mean Square
RTIC	Real-Time Information in the Cockpit
RTU	Replacement Training Unit
RWR	Radar Warning Receiver
SA	Situation Awareness
SAM	Surface-to-Air Missile
SCL	Set Clearance Limit
SPMR	Simulation Project Modification Request
SRL	Systems Research Laboratory
SWAT	Subjective Workload Assessment Technique
SWORD	Subjective Workload Dominance
TA	Terrain Avoidance
TEMP	Temperature
TEWS	Tactical Electronic Warfare System
TF	Terrain Following
TFR	Terrain Following Radar
TPC	Tactical Pilotage Chart
TR	Technical Report
TSD	Tactical Situation Displays

UFC	Up Front Control
VFR	Visual Flight Rules
WL/FIGP	Wright Laboratory Advanced Cockpits Branch
WPNS	Weapons
WSO	Weapon Systems Officer
3-D	Three-Dimensional

1. INTRODUCTION AND SUMMARY

The information in this section provides a brief background on the IMPACT Program, the objectives of the advanced technology experiment, the scope of this report, and a summary of the procedures and results of the experiment.

1.1 Background

The Wright Laboratory Advanced Cockpits Branch (WL/FIGP) Integrated Mission/Precision Attack Cockpit Technology (IMPACT) program focuses on determining cockpit and pilot-vehicle interface (PVI) requirements for a single-seat, multi-role fighter aircraft performing at night and in adverse weather. During the Mission Analysis and Interface Requirements phase of the IMPACT Program, Air Combat Command mission requirements and current technologies were assessed. Based on the requirements and the associated high workload segments, the air interdiction (AI) scenario was selected by the IMPACT team as the starting point for analyzing the overall IMPACT cockpit design requirements. The F-15E two-seat strike fighter was identified as the baseline weapon system because it is currently the US Air Force's most capable aircraft in performing a multi-role mission in adverse weather and at night.

Through mission decomposition and analysis the IMPACT team determined that the ingress, attack, and egress segments of the AI mission contained the highest levels of workload and therefore warranted the greatest attention. With the mission segments identified, both function and task analyses were conducted to understand the allocation of required functions for the pilot, the weapon systems officer (WSO), and the aircraft systems for the F-15E platform. Mission function timelines were developed to graphically determine which areas of the mission required multiple functions/tasks to be accomplished simultaneously. In addition to the two-seat F-15E mission timeline, which includes a pilot and a WSO, a separate mission timeline was developed for a conceptual, single-seat version of that system. To facilitate the transition to a single-seat aircraft, it was essential for the experiment team to understand how these functions were allocated in the two-seat system.

By understanding current requirements and limitations, the IMPACT team performed an in-depth review of advanced technologies to identify possible solutions. These technologies included advances in sensors, controls and displays, weapons, and pilot aiding techniques. The evaluation of these technologies led to the Preliminary Cockpit Design and Trade Studies event. The design objective of this event is to develop a cockpit that exhibits equal or better operational and performance capabilities when compared to the F-15E in the AI mission. Advancements in cockpit technology will be integrated into the IMPACT cockpit to achieve improvements in operational capability.

The first IMPACT experiment was a Role Playing Exercise, whose objectives were to (1) identify workload associated with an AI mission at night under adverse weather, (2) identify possible cockpit-related technologies that could improve the overall effectiveness of a single-seat fighter performing an interdiction mission at night under adverse weather, and (3) verify the "Role Playing" methodology. Workload levels associated with an AI mission at night and under the weather were determined, and advanced technologies were identified that had the highest potential for reducing workload, increasing situation awareness (SA), and improving mission effectiveness. Four technologies that were determined as having the greatest potential were sensor fusion, data link, head steered sensor, and the helmet-mounted display (HMD) (Montecalvo et al., 1994).

1.2 Objectives

This Advanced Technology Integration Experiment focused on three technologies: an HMD, large tactical situation display (TSD), and directional audio. Each technology was integrated into the IMPACT cockpit and its ability to aid a pilot in visually acquiring surface and air threats and ground targets was assessed.

The overall objectives of this experiment were to

- Evaluate pilot threat acquisition performance in two cockpit configurations: a baseline cockpit (based on the F-15E, and hereafter referred-to simply as the Baseline) containing

the formats necessary to accomplish the experimental tasks, and the IMPACT cockpit containing the HMD, directional audio, and 10" x 10" TSD advanced technologies.

- Evaluate pilot flight performance while attacking ground targets in each cockpit configuration.

- Evaluate pilot workload and SA for both threat acquisition and weapon delivery for each cockpit configuration.

- Identify strengths and weaknesses of the IMPACT configuration and the individual advanced technologies, using post-mission and post-experiment questionnaires.

Expectations were that the advanced technologies incorporated into the IMPACT cockpit would result in improved performance for acquisition of surface and air threats. One hypothesis was that, because of multiple sources of threat cueing, the time to acquire threats would be lower for the IMPACT cockpit as compared to the baseline. Also, expectations were that the IMPACT cockpit would result in smaller flight parameter deviations as compared to the baseline because the multiple sources of cueing would facilitate quicker threat acquisition outside the HUD field-of-view (FOV), thus allowing the pilot to quickly return to the flying task.

Another hypothesis was that the IMPACT cockpit would result in smaller groundspeed, flight path, and attack axis deviations than the baseline during the Weapon Delivery Phase. Through the use of the HMD in the IMPACT cockpit, the pilot would have a greatly expanded FOV as compared to the simulated baseline Low Altitude Navigation and Targeting Infra-Red for Night (LANTIRN) HUD. This expanded FOV was expected to facilitate optimized aircraft maneuvering for a faster and smoother alignment onto attack parameters.

Finally, it was expected that workload would be lower for IMPACT than the baseline during threat acquisition and weapon delivery. The anticipated reduction of workload when acquiring threats and attacking targets can be attributed to the advanced technologies.

1.3 Scope of Report

This report provides descriptions of the advanced technologies evaluated in this experiment, an explanation of the methodology employed to analyze those technologies, the results of the experiment, and a discussion of those results.

1.4 Executive Summary

Three advanced technologies were integrated into the IMPACT cockpit: an HMD, directional audio, and a 10" x 10" TSD incorporating Real Time Information In The Cockpit (RTIC). The ability of these technologies to aid a pilot in visually acquiring surface and air threats and ground targets was assessed because in two-seat fighters, the pilot and the WSO share responsibility for these tasks.

The subject pilots were briefed on the experiment and were trained in the simulator to fly both cockpit configurations (baseline and IMPACT). At the completion of training, they participated in eight data collection runs. The scenario was a night, under the weather interdiction mission to attack a SCUD missile launcher. The pilots flew a pre-briefed route to a pop-up weapon delivery. Along the route, they were tasked to visually acquire threats that had locked onto the aircraft. The pilots reported their workload during the mission using the Subjective Workload Assessment Technique (SWAT). In addition, flight performance data were collected during each simulator run.

Data analysis consisted of the determination of threat acquisition time, threat acquisition success rate, flight performance during threat acquisition and weapon delivery, workload, and SA. Questionnaires and interviews focused on the comparison of the two cockpits and the influence of each individual technology on the overall IMPACT objectives.

The results of this experiment show that the implementation of the HMD, directional audio, and large TSDs decreased the amount of time required for the pilot to visually acquire threats. Also, approximately 20% more threats were acquired and pilot workload was lower in the IMPACT cockpit. The pilots also reported that their situation awareness was higher in the

advanced cockpit than in the baseline cockpit. In the area of flight performance, pilots encountered fewer deviations in altitude, airspeed, and heading in the IMPACT configuration.

2. DESCRIPTIONS OF ADVANCED TECHNOLOGIES

For a pilot operating a single-seat, multi-role fighter to be as effective as an F-15E crew in the night interdiction mission, advanced technologies are necessary to perform the inflight tasks currently accomplished by the F-15E WSO. The technologies must aid the pilot in threat reaction, target designation, and weapon delivery. The integration of the technologies should decrease high workload demands on the pilot while increasing SA.

An HMD, 3-D audio, and a large TSD were identified in a previous experiment (Montecalvo et al., 1994) as having the potential to assist a pilot in a single-seat, multi-role aircraft attempting to acquire surface/air threats and ground targets. The appropriate application of these advanced technologies may provide the single-seat pilot with equal or better SA with respect to threat location than is now possible with two crew members.

2.1 Helmet-Mounted Display

An HMD can be beneficial in replacing the visual search capability that is lost when crew size is reduced from two to one. In many cases, a quick visual acquisition of an attacking fighter or a surface-to-air missile in flight is absolutely essential to survival.

Literature reviews were conducted to gather information concerning the current state of development and recommended mechanization for each advanced technology. A significant amount of work has been performed in the area of HMDs, making it necessary to limit the literature review to programs and studies that contain (or define) functional and operational design criteria. In addition, through in-house meetings, the decision was made to focus only on those items that were necessary to help facilitate off-boresight cueing, tracking, and designation.

Advanced technologies have the potential to assist the single-seat pilot during night weapons deliveries. When Low Altitude Navigation and Targeting Infra-Red for Night (LANTIRN)-equipped fighters execute level, climbing, and diving visual weapon deliveries at night, using the forward looking infra-red (FLIR) for target acquisition, they must fly directly towards the target for the duration of the weapon delivery maneuver because of the FLIR's

narrow field-of-view (FOV). Therefore, the pilot flies a very predictable path to the target, increasing the probability that enemy threat systems can engage the aircraft. One alternative currently used in daylight visual flight rules (VFR) conditions is to perform an off-axis attack where the pilot's weapon delivery axis is not necessarily aligned with the approach course. This alternative complicates the enemy's problem, but is very difficult to accomplish at night with today's technology. The incorporation of advanced concepts such as HMD with a head-steered FLIR may provide the pilot sufficient SA to allow off-axis target attack without increasing workload.

HMD symbology was developed based on the following operational requirements: early visual acquisition of threats/targets; maintaining visual acquisition of threats/targets; maintaining visual acquisition of friendly aircraft; and the capability to closely monitor ownship energy state. These operational requirements were consistent with those determined by operational fighter pilots (Barnes, 1989). Based on these requirements, the working group identified symbology and mechanizations using the Night Attack Program Pilot-Vehicle Interface Studies (Royer, 1991 and 1992) as initial references. Once the symbology and the overall mechanizations were selected, Simulation Project Modification Requests (SPMRs) were developed to document the functionality and design specifications for both cockpits and their display formats. Appendix A provides a copy of the SPMRs used for this experiment.

2.2 3-Dimensional Audio

Potential benefits of 3 dimensional audio are detection and identification of threats, targets and wingmen, as well as navigation aids such as terrain alerts. The current drive towards displaying real-time information requires additional complex visual displays that further increase the perceptual and cognitive demands on the pilot (Dolan et al., 1993). To address this issue, other modalities such as the auditory channel are being investigated in an attempt to decrease the demand on visual resources.

The benefits of 3 dimensional audio centers around two issues. First, it may provide a more intuitive indication of threat location with respect to the pilot's head. Second, proper

integration should reduce demand on the pilot's visual resources. This reduction should be realized because concurrent tasks that share the same pool of resources (e.g., two visual tasks) tend to interfere with each other more than concurrent tasks that do not share the same resources (e.g., a visual task and an auditory task) (Wickens, 1984).

Directional audio systems encode naturally occurring spatial information into an audio signal and present a sound source that can vary in azimuth over stereo headphones incorporated into the pilot's helmet. To the pilot, the encoded signal sounds as if it is originating from a particular location. As the pilot changes head orientation, the relative position of the sound source is updated to make the sound appear stationary with the listening environment. Patterson et al., (1993) surveyed 76 experienced military pilots regarding the application of 3-D audio. Most pilots preferred localized audio signals to the present non-localized audio, especially for wingman communications and threat audio. Based on Patterson's research, a directional audio system that provided localized tones for threat warnings was incorporated into this IMPACT experiment.

2.3 Large Tactical Situation Displays

Until recently, display technology has been limited by smaller (5" x 5" or 4" x 4") displays. In an effort to promote greater SA, a large 10" x 10" TSD was developed for this experiment. The large TSD simulates the advanced techniques of fusing data from multiple sensors to present a composite set of data on a single display format without introducing unacceptable symbology clutter as in a 4 or 5 inch display.

TSD symbology and color coding were developed and incorporated into the IMPACT cockpit. SPMRs were developed to document the functionality and design specifications of each proposed format (see Appendix A). The TSD formats were consistent with display elements reported in research conducted by Way et al., (1987), Galvin and Pecha (1992), and Vanderbach et al., (1993)

3. METHODOLOGY

In this experiment, subject pilots flew a simulator that was reconfigurable as both the baseline and the IMPACT cockpits. Advanced technologies were integrated, subjects were trained, and data were collected in the simulator and through questionnaires and post-mission interviews. Measures of effectiveness, performance, workload, situation awareness (SA), and subjective data were determined and analyzed.

3.1 Subjects

Eighteen male pilots participated as subjects. Total operational aircraft flight time for the pilots ranged from 770 to 3470 hours (mean = 2618). Sixteen of the pilots had fighter aircraft experience and two had B-52 experience. Appendix B provides more details concerning pilot flying experience.

3.2 Apparatus

The apparatus consisted of the cockpit simulator, the three advanced technologies (HMD, TSD, and directional audio), the head tracking device, the out-the-window visual scene projection screen, and the experimenter's station. Materials used to train the subject pilots and the post-mission questionnaires were also part of the experiment apparatus.

3.2.1 Cockpit Simulator

The evaluation was conducted in the Crew System Integration Laboratory's (CSIL) Manned Combat Station (MCS), which was reconfigurable as either the baseline (F-15E front panel) cockpit or the IMPACT cockpit (see Figure 1). The MCS was a single seat cockpit "shell" about the size of an F-16. A single Matsushita 27" color monitor presented the head-down, dynamic, non-interactive display formats for both cockpit configurations. Flight control and limited hands-on-throttle-and-stick (HOTAS) switching was provided via F-15 type throttles and a force side-stick controller with an F-15 grip (see Appendix A, SPMR 1.1).

Figure 2 shows the baseline cockpit configuration (TO 1F-15E-1, 1993). Each frame consisted of the F-15E up-front control (UFC, top center in figure), left multi-function display (MFD), center MFD, and right MFD. Additional displays included the fuel quantity and engine instrument gauges. The frames were developed using Designer software, and were displayed on the monitor using a Silicon Graphics Onyx Reality Engine 2 system. F-15E heads-up display (HUD) symbology (TO 1F-15E-34-1, 1993) and the outside world forward-looking infra-red (FLIR) image, also generated by the Silicon Graphics system, were presented on the Barco projection system. Only those controls, displays, and formats necessary to perform the threat and target acquisition tasks for the experiment were available for pilot use.

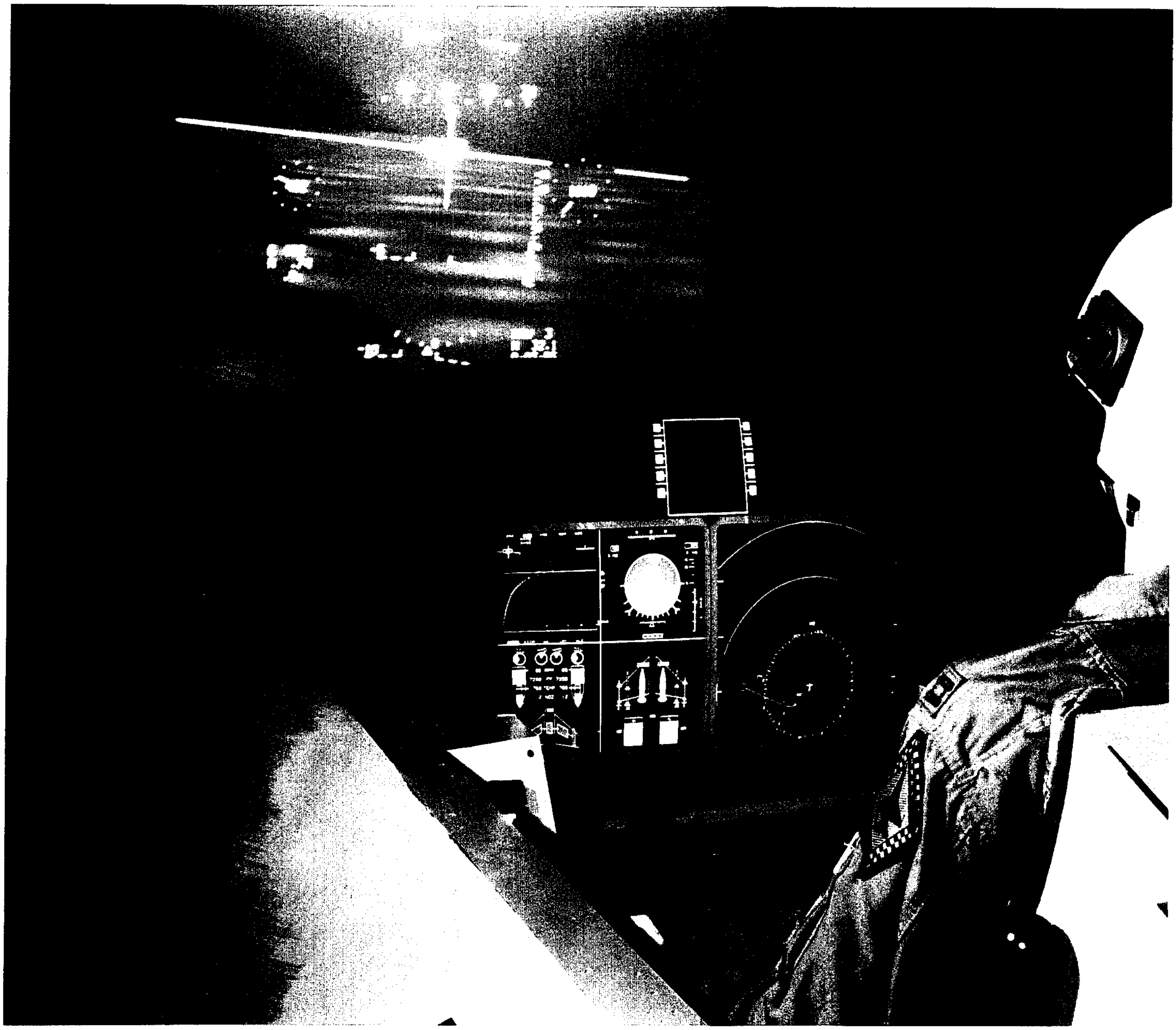

Figure 1. CSIL MCS Flight Simulator

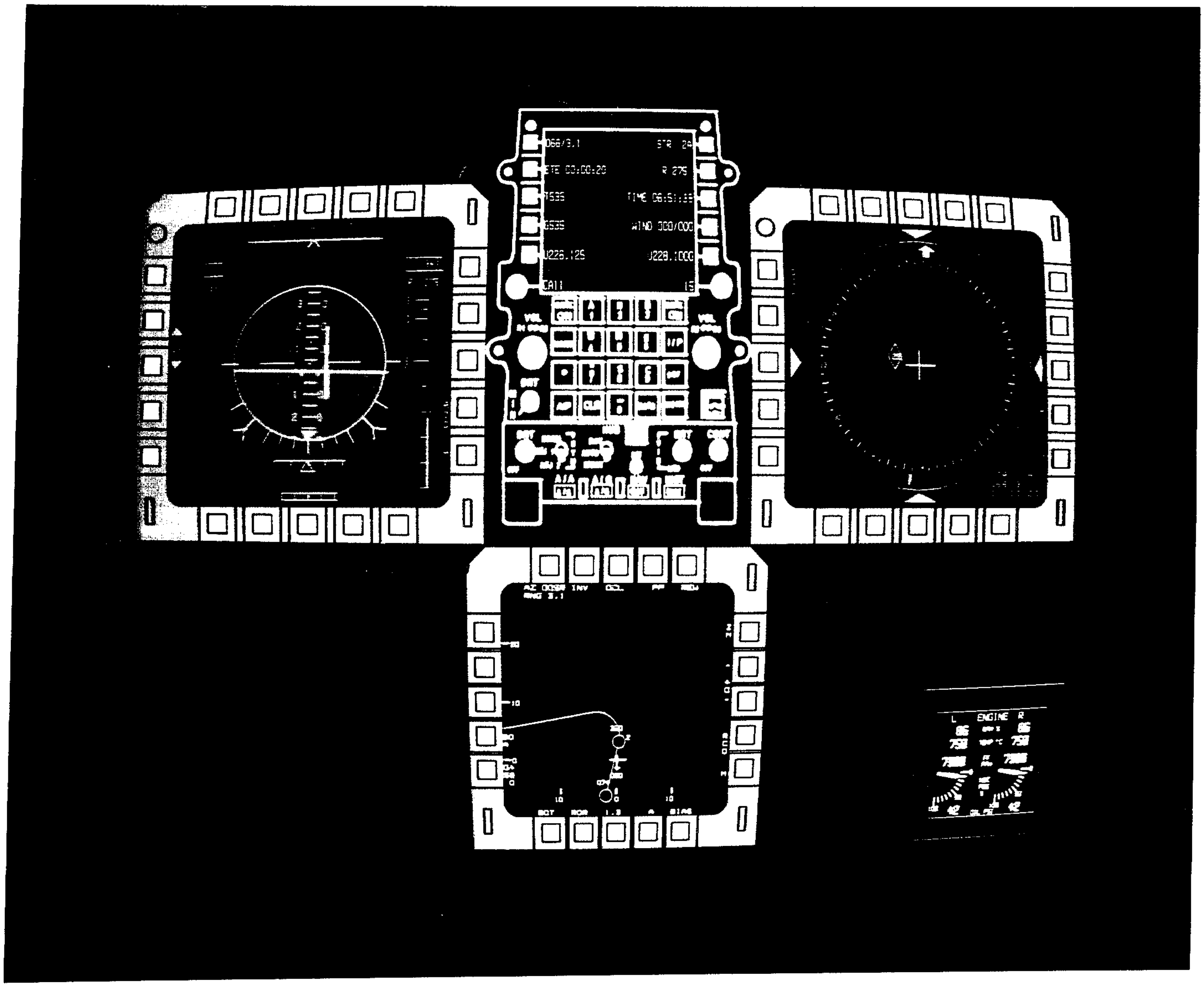

Figure 2. Baseline Cockpit Configuration

Figure 3 shows the IMPACT cockpit configuration. Two 10" x 10" displays and an upfront controller were presented on the head-down monitor. F-15E HUD symbology and the outside world FLIR image were presented on the Barco projection system. The IMPACT cockpit also integrated the HMD and directional audio system. The formats used in the experiment and the associated operational descriptions are provided in Appendix A.

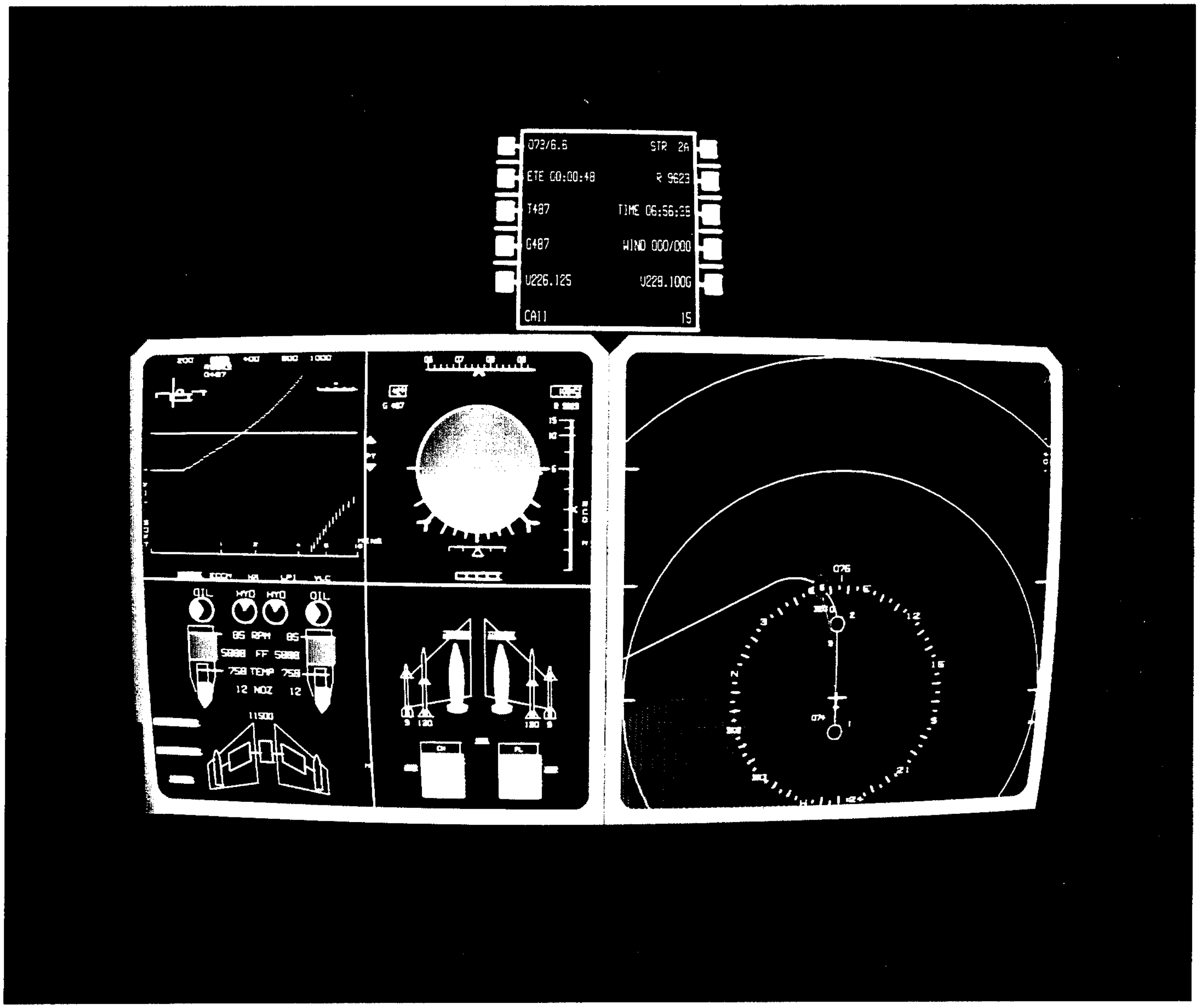

Figure 3. IMPACT Cockpit Configuration

3.2.2 Helmet-Mounted Display

The HMD was a monochrome Kaiser SIM EYE 40 consisting of a helmet, a binocular HMD, and an electrical interface unit. The system field-of-view (FOV) was 40^0 circular with 100% overlap. The cathode ray tubes (CRTs) were driven at a rate of 60 Hertz, non-interlaced with a resolution of 1280 x 1024. Figure 4 shows the IMPACT HMD symbology format.

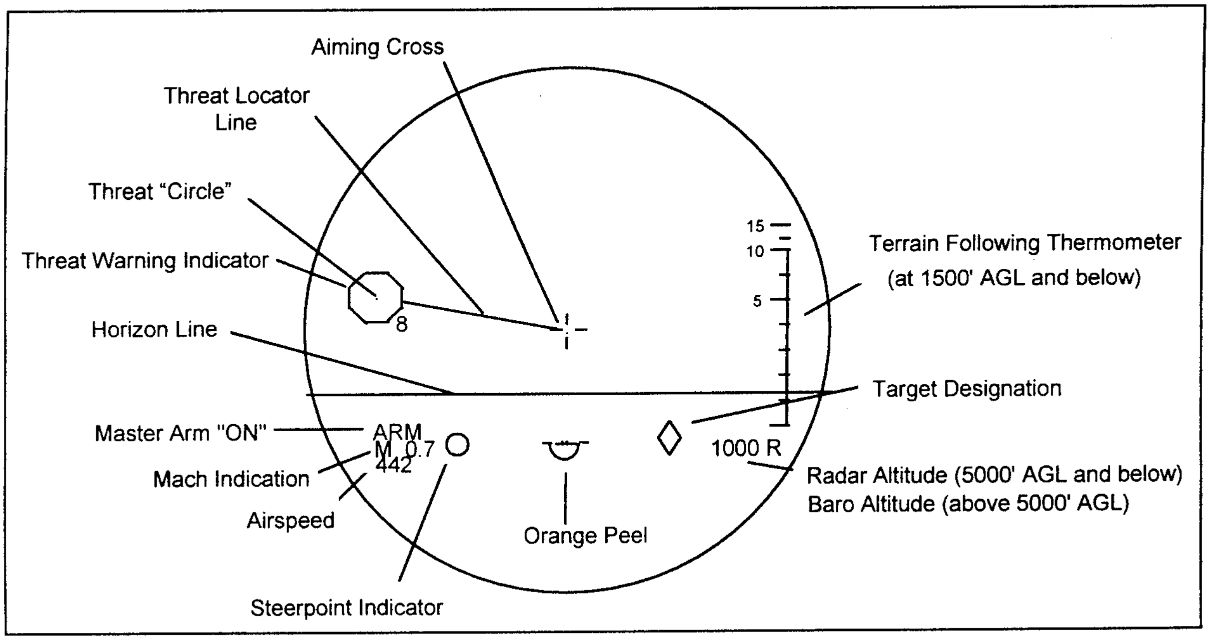

Figure 4. IMPACT HMD Symbology

The HMD was used as a "virtual dome" in the baseline condition and only displayed the various surface and air threats (Threat "Circle" in Figure 4). Flight and threat/target cueing symbology were <u>not displayed</u> on the HMD in the baseline configuration. Conversely, the HMD for the IMPACT cockpit <u>did</u> display flight and threat/target cueing symbology as well as the surface and air threats (everything in Figure 4).

3.2.3 Directional Audio

The Auditory Localization Cue Synthesizer (ALCS) was designed by Armstrong Laboratory (AL) in conjunction with Systems Research Laboratory (SRL). This audio system provided two channels: one channel for azimuth cueing and the other for elevation cueing. The

head-related transfer functions filter sound through any one of 272 speaker locations (separated by 15°) with an update rate of 50 Hz. Because it was necessary to communicate with the pilot during the experiment, one channel was devoted to the intercom, thus eliminating elevation cueing capability. However, the decreased demand on the audio processor, as well as the decrease in speaker separation within the head-related transfer function (from 15° to 1°), allowed a commensurate increase in azimuth cueing resolution and greatly enhanced the directional audio capability.

3.2.4 Head Tracking Device

The Flock of Birds 6-D Multi-Receiver/Transmitter Tracking Device was used to measure the pilot's head X, Y, Z position coordinates and orientation angles and provided signals to both the HMD and the directional audio system. The signal transfer baud rate was 32K.

3.2.5 Out-The-Window Visual System

Simulated FLIR imagery and HUD symbology for both cockpits were generated by the Silicon Graphics system and were displayed on a Barco Retrographics 801. Once the pilot maneuvered the aircraft to put the target within the simulated HUD FOV, the target was also displayed on the Barco. Refer to Figure 5 for the HUD symbology.

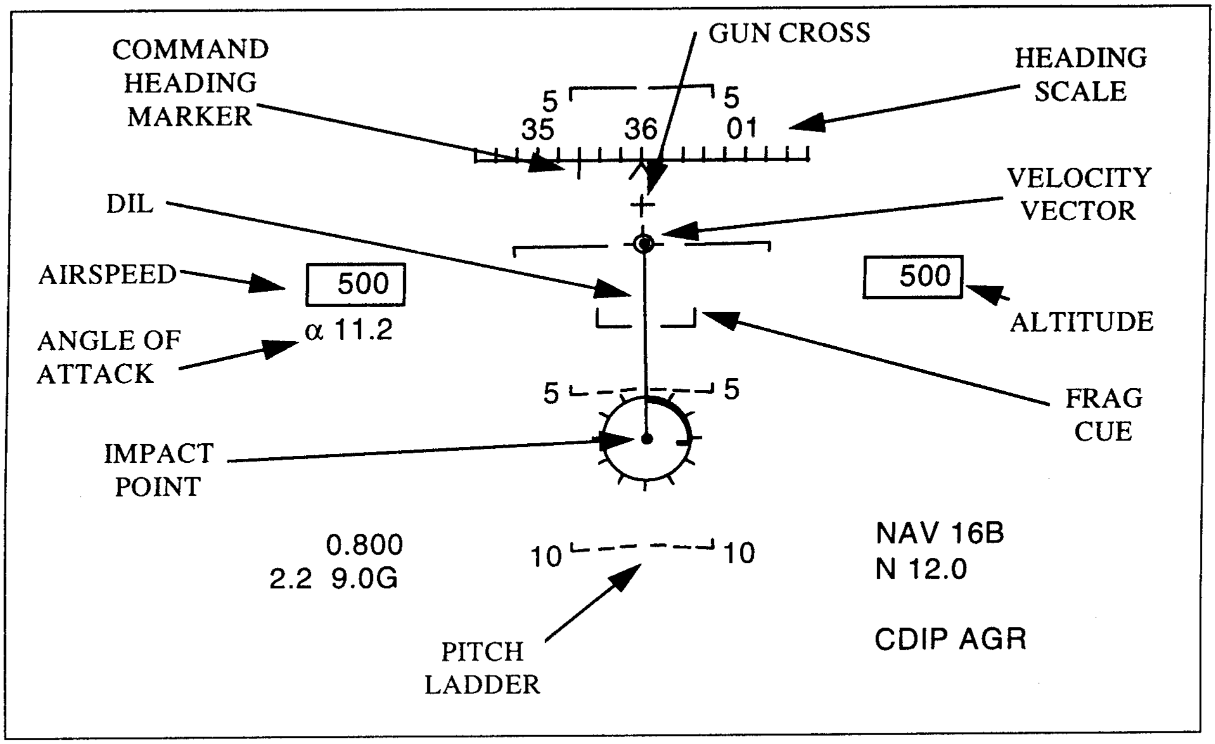

Figure 5. HUD Symbology

3.2.6 Experimenter's Station

At the experimenter's station, one experimenter could monitor the simulation, control the cockpit configuration, and start, freeze, and restart the simulator as required. This experimenter also controlled the sequencing of the events based on the script, route, and pilot actions. A second experimenter, stationed immediately behind the simulator, observed the actions of the pilot, provided assistance if the pilot had difficulty with the simulator or the helmet, and asked the pilot questions at the end of each trial. Both experimenters and the subject communicated via intercom.

3.2.7 Training Material

The training material included a briefing on the objectives of the experiment, a description of the advanced technologies, a briefing on the baseline and IMPACT displays and control suites, and a description of the experimental procedures. These materials were used to familiarize the subjects with the experiment procedures and simulator operation.

3.2.8 Questionnaire Material

The questionnaire material included a post-mission data probe, an out-brief data probe, and a methodology/procedures questionnaire. Examples of these questionnaires are provided in Appendix C. The questionnaires were used to collect subjective data on the advanced technologies, their implementation, and their effects on performing the mission.

3.3 Procedures

The test procedures consisted of the training and testing of the pilots, the experimental design, and the collection of the data. Each pilot reported to the laboratory between 0800 and 0830 for introductory briefings and training on experimental procedures and equipment. After the training session was completed, each pilot was given a practice session in the simulator to provide familiarity with the mission profile and procedures. Data collection, which consisted of performance data, subjective data, and questionnaire data followed the training session. The subjects finished the day at approximately 1630 hours.

3.3.1 Training

The training program, which was designed to help all the pilots understand their roles and responsibilities during data collection, consisted of approximately 1.5 hours of ground training and 1.5 hours of simulator familiarization training. The ground training included administrative items such as the facility and safety considerations and an introductory briefing. The briefing included a description of the following information: both cockpit configurations, HUD and HMD symbology, depictions of threats and targets, mission scenario, and test procedures.

All pilots were introduced to the Subjective Workload Assessment Technique (SWAT), which is a method of collecting workload data while the pilot is flying the simulator. The introduction to SWAT included written instructions, verbal instructions, and the procedures that the pilots should use during the data collection runs to relate their workload levels to the

experimenters.[1] The training session concluded with simulator familiarization, in which the pilots were given the opportunity to practice Threat Acquisition and Weapon Delivery functions while becoming accustomed to flying the simulator.

3.3.2 Testing

At the completion of training, each pilot participated in eight data collection runs of approximately 12 minutes each. The scenario was a night, under the weather, air interdiction mission attacking a SCUD mobile missile launcher. The pilot was required to navigate along a pre-briefed, pre-planned route and to perform a pop-up weapon delivery using a simulated FLIR system. The pilot was instructed to fly the HUD flight path marker in the manual terrain following (TF) box to maintain terrain clearance during the low-level segment of the mission. Manual TF was flown to induce additional workload. Figure 6 shows a graphic of the air interdiction (AI) mission scenario.

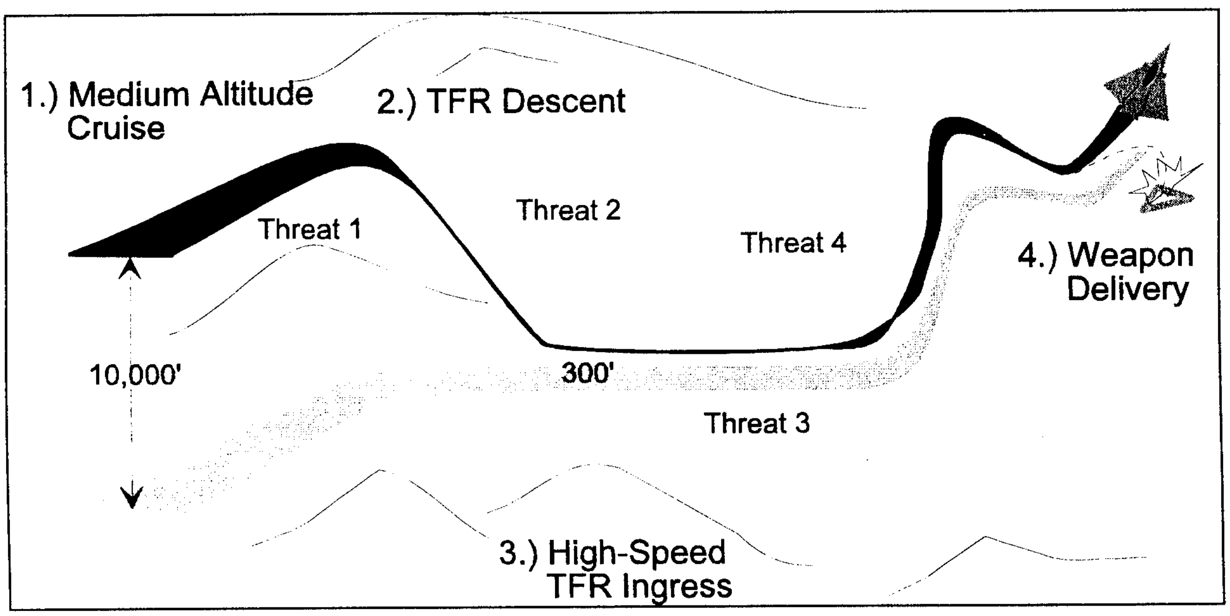

Figure 6. Pictorial Description of the Mission

---

[1] Each pilot was required to sort a set of 27 cards. The cards represented the various dimensions of SWAT, from lowest to highest workload. The resulting card sort was then subjected to a statistical technique (conjoint measurement technique) to develop a baseline workload scale, from 0 (lowest workload) to 100 (highest workload), for each subject pilot (Reid, 1989).

The mission was divided into the following four phases:

1) Medium Altitude Cruise started at the beginning of the experiment, ended at the first turn point and was flown at 10,000 feet MSL, at 480 knots.

2) Terrain Following Radar (TFR) Descent started at the first turn point and ended at the beginning of the low-level portion. The system software commanded the pilot to fly 45^0 of bank and 12^0 of dive during the descent while increasing the aircraft airspeed to 540 knots. The pilot leveled the aircraft at 300 feet above ground level (AGL).

3) High-Speed TFR Ingress started at the end of the TFR Descent Phase and ended at the completion of the turn to the initial point. This segment was flown at 300 feet AGL and 540 knots.

4) Weapons Delivery/Attack started at the beginning of target tracking and ended at weapons release. The "optimal" attack profile, against which actual pilot performance was compared, required 10° of dive, 540 knots groundspeed, and maintaining an attack course specified at the beginning of each trial. This course was between 8,588 and 4,100 feet from the target.

To preclude anticipatory effects, a wide range of values was established for the location of the threats and ground targets. During data collection, pilots never saw the same threat or target location more than once. Refer to Appendix D for values that were used during testing.

To assess pilot threat acquisition and weapon delivery performance with and without the advanced technologies, each pilot encountered four threats along the route and then attacked one target. Threats and targets were categorized as either "easy" or "hard." The reasons for the two threat/target types were operational realism and the avoidance of learning effects.

Threat difficulty was based on the position of the threat with respect to the aircraft when the threat first appeared. Easy threats were defined as being in the pilot's forward hemisphere from 0° to ± 90° in azimuth and from 0° to ± 50° in elevation. The hard threats were defined as being in the pilot's aft hemisphere, from 90° to 180° in azimuth (left and right hand sides of the

cockpit) and from 50° to 90° in elevation. Threats were simulated as either surface-to-air missiles or air-to-air missiles and were presented on the HMD as stationary small green circles.

Easy targets were located within 10° of the run-in course at the start of the pop-up maneuver, and the hard targets were located outside the HUD FOV (between 35° and 45° from run-in course) at the pop-up point. All ground targets were computer-generated depictions of SCUDs and appeared on the simulated LANTIRN HUD visual scene. Launcher positions were stationary during each trial.

In the baseline condition, threat warnings were displayed visually on the tactical electronic warfare system (TEWS) and aurally through the radar warning receiver system. The pilot obtained general azimuth information about the threats by looking at the TEWS display and was then required to look outside the cockpit in the appropriate direction for the threat. As the pilot's head turned to bring the threat within the HMD FOV, the threat (a small green circle) was displayed on the HMD. Once the threat was acquired, the pilot activated the chaff dispense switch on the control stick, simulating countermeasures activity. At this point, the threat disappeared and a time stamp was collected.

Visual acquisition of threats in the IMPACT cockpit was accomplished in a similar manner, however, the pilot received additional cueing information. Threat warnings were displayed visually on the TSD and aurally (via tones) through the directional audio system. Figure 7 depicts the TSD threat warning symbology. In addition, threat locator symbology was provided through the HMD. Because of the additional cueing information, the IMPACT team hypothesized that the pilot would be able to acquire threats with less maneuvering of the aircraft. After visually acquiring the threat circle, the pilot dispensed chaff to simulate defeating the threat.

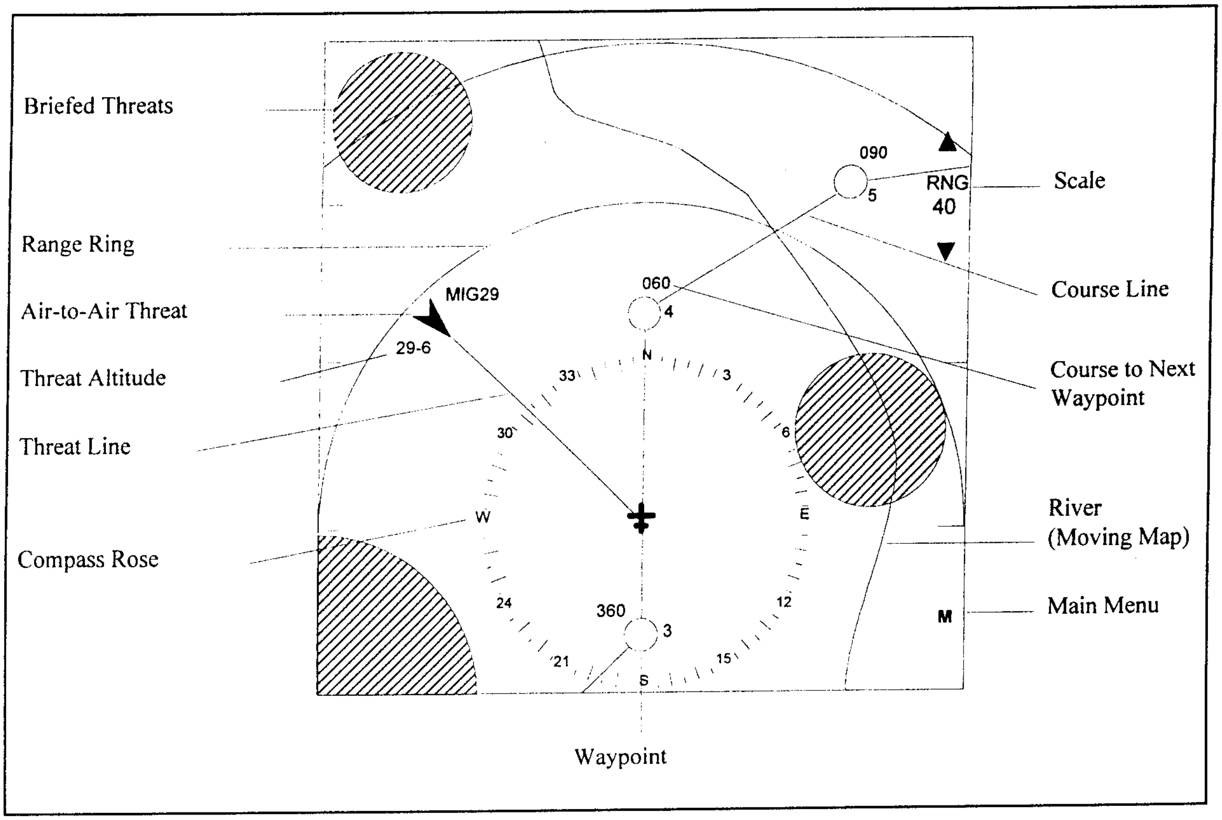

Figure 7. TSD Symbology Formats

To test pilot flying performance during the attack segment with and without the advanced technologies, each pilot ended each mission by flying a pop-up, weapon delivery attack profile using the FLIR system on a SCUD missile launcher. The pilot flew to the pre-briefed pop-up point, and then climbed to the roll-in altitude for a 10° low-angle/low-drag dive bomb delivery. The target was displayed on the Barco projection system after the pilot had maneuvered to put the target within the simulated FLIR/HUD FOV. In the baseline configuration, the pilot located the target and accomplished the weapon delivery using only the cueing information provided by the HUD symbology. In the IMPACT cockpit, the pilot used both the HUD and the off-boresight cueing symbology on the HMD to locate the target and deliver the weapon. In both configurations, once the target was located, the pilot was required to maneuver so that the optimized weapon delivery profile could be accomplished.

Finally, at the completion of each trial and at the completion of the testing session, questionnaires were used to collect subjective data on the cockpit configurations and the implementation of the advanced technologies.

3.4 Experimental Design

A 2 x 2 (Cockpit Configuration by Threat Difficulty) blocked counterbalanced design was used in this experiment, and the details are provided in Appendix D. Threat difficulty was balanced so that the overall difficulty for an entire trial was approximately the same for all trials. Two easy threats and two hard threats appeared in every trial, and the presentation order was counterbalanced across missions to eliminate systematic learning effects. Finally, the difficulty of ground targets was blocked across pairs of successive missions, providing an equal number of easy and hard target engagements.

3.5 Data Collection

Objective measures of performance were used to determine the collective contributions of the advanced technologies in reducing threat visual acquisition times and flight performance during weapon delivery. Flight path tracking accuracy during the cruise, low-level and attack portions of the mission was collected. Subjective measurements were used to determine the contributions of the individual technologies for accomplishing the AI mission tasks and to identify baseline versus IMPACT pilot workload.

Five types of data were collected: Measures of Effectiveness (MOE), Measures of Workload (MOW), Measures of Situation Awareness (MSA), Measures of Performance (MOP), and subjective data. MOEs provided a relative assessment of global pilot-vehicle system performance across experimental conditions. MSAs provided a means to compare relative pilot situation awareness in each cockpit configuration. MOPs provided a relative measure of pilot performance on specific tasks for various experimental conditions. MOWs assessed mental workload at various points in the mission. MOWs can be correlated with MOPs and MOEs to identify performance and effectiveness decrements in high-workload conditions. Finally,

subjective data included pilot ratings and comments that were obtained through questionnaires. See Table 1 for a summary of the data collected from each mission phase.

Table 1. Data Collected From Each Mission Phase

PARAMETER	MISSION PHASE			
	Medium Altitude Cruise	TFR Descent	High-Speed TFR Ingress	Weapon Delivery
Ground/Airspeed (knots)	√		√	√
Altitude (feet)	√			
Course (degrees)	√		√	√
Dive Angle (degrees)		√		√
TFR Command (milliradians)			√	
Threat Acquisition Time (sec.)	√	√	√	
Workload (SWAT)	√	√	√	√

3.5.1 Measures of Effectiveness

The two measures of effectiveness in this experiment were threat acquisition time and threat acquisition success rate. The threat acquisition time was defined as the interval starting with threat onset via auditory tone and visual display and ending with the pilot dispensing chaff using the paddle switch on the control stick. Pilots were instructed to stabilize the threat symbol within the HMD FOV prior to dispensing chaff. If not acquired, the threat would disappear after 20 seconds. The "time-out" value was based on the experience of subject-matter experts, who stated that the upper bound for a surface-to-air or air-to-air threat engagement approaches 20 seconds. The threat acquisition success rate was defined as the number of threats acquired within the allotted 20 seconds for both cockpit configurations.

3.5.2 Measures of Workload

The Subjective Workload Assessment Technique (SWAT) was used to collect subjective pilot workload data after each of the four threats and after weapon delivery. SWAT assumes that

workload is composed of three dimensions: time stress, mental effort, and psychological stress. Time stress refers to the amount of time available to an operator to accomplish a task and is rated on a 3-point scale ranging from 1 (often have spare time) to 3 (almost never have spare time). Mental Effort refers to the amount of attention or concentration that is required to perform a task and is rated on a 3-point scale ranging from 1 (very little conscious effort) to 3 (excessive mental effort and concentration is required). Psychological Stress refers to the presence of confusion, frustration, or anxiety associated with a task and is also rated on a 3-point scale ranging from 1 (little confusion, risk, frustration, and/or anxiety exists and can be easily accommodated), to 3 (high to very intense stress due to confusion, frustration, or anxiety) (Reid, 1989).

3.5.3 Measures of Situation Awareness

A customized Subjective WORkload Dominance (SWORD) form was used to gather SA measures and to compare relative pilot SA in the different cockpit configurations and tasks. The SWORD form for this experiment is provided in Appendix C and is based on work performed by Vidulich (1989). The relative judgments were used to generate ratings for each cockpit configuration and task, which were statistically analyzed. Pilots completed a SWORD rating form during the post-experiment questionnaire session.

3.5.4 Measures of Performance

Relevant measures for the different mission phases were collected to determine flight path performance during threat acquisition. The measures included aircraft altitude, course, groundspeed, dive angle, and terrain following (as applicable) for the Medium Altitude Cruise, TFR Descent, and High-Speed TFR Ingress Phases. Deviations from the required flight path were collected and analyzed.

The aircraft's vertical flight path, attack course axis, and groundspeed were measured to determine flight performance during weapon delivery. Pilot performance was compared to the pre-briefed "optimal" attack flight path, and deviations from the optimal path were collected and analyzed. The flight performance results are provided in Section 4.

3.5.5 Subjective Data

The pilots were administered post-mission interviews, and each completed a pilot information survey and questionnaire at the end of the experiment. Questionnaires and interviews focused on cockpit comparisons and the influence of each individual advanced technology on overall program objectives (see Appendix C).

4. RESULTS

The results of this experiment address the objectives stated in Section 1, which were to evaluate pilot threat acquisition performance, flight performance, workload, and SA in the baseline and IMPACT cockpits, as well as to determine the relative strengths and weaknesses of the advanced technologies. Measures of effectiveness for the configurations include the time required to acquire threats and the threat acquisition success rate. Measures of pilot flight performance while acquiring threats and attacking ground targets include deviations from planned altitude, course, and groundspeed. Pilot workload and situation awareness associated with the threat acquisition and weapon delivery functions of the missions for both cockpit configurations were collected and are provided in this section. Finally, the subjects' opinions of the strengths and weaknesses as to how the advanced technologies were implemented in this experiment are summarized. Statistical results are provided in Appendix F.

4.1 Measures of Effectiveness

To reiterate, the measures of effectiveness included the threat acquisition time and the threat acquisition success rate. Threat acquisition time was the period of time from the initial appearance of the threat until the pilot visually acquired the threat and dispensed chaff. The threat acquisition success rate was the number of threats acquired divided by the number of threats presented.

4.1.1 Threat Acquisition Time

A 2 x 2 (Cockpit Configuration by Threat Difficulty) repeated measures ANalysis Of VAriance (ANOVA) was performed on the threat acquisition time data. The threat acquisition time was significantly shorter for the IMPACT cockpit than for the baseline in both the easy threat condition and the hard threat condition (see Figure 8).

The threat acquisition time was significantly shorter with the IMPACT cockpit (8.43 sec.) than for the baseline (12.95 sec.). Also, threat acquisition was significantly shorter for the easy threats (8.28 sec.) than for the hard threats (13.10 sec.).

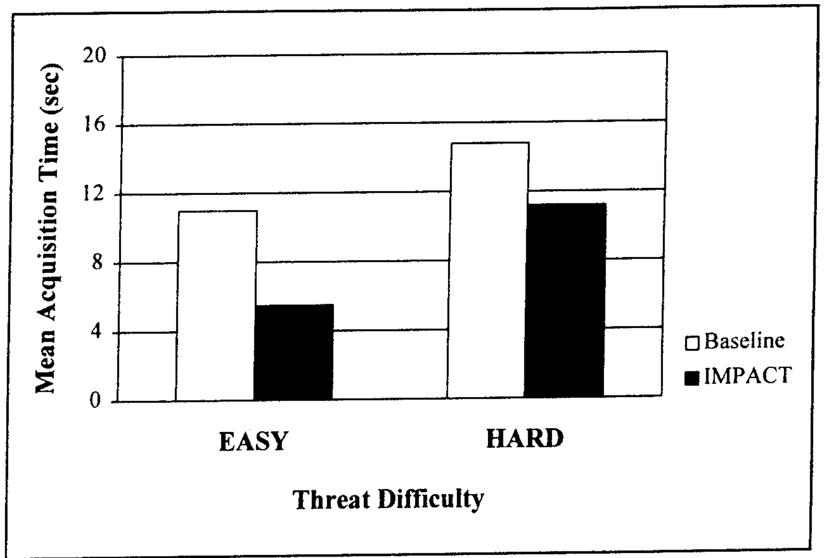

Figure 8. Mean Threat Acquisition Time

4.1.2 Threat Acquisition Success Rate

A 2 x 2 (Cockpit Configuration by Threat Difficulty) repeated measures ANOVA was performed on the threat acquisition success rate data. As shown in Figure 9, approximately 20% more threats were acquired with the IMPACT cockpit than with the baseline throughout the entire mission.

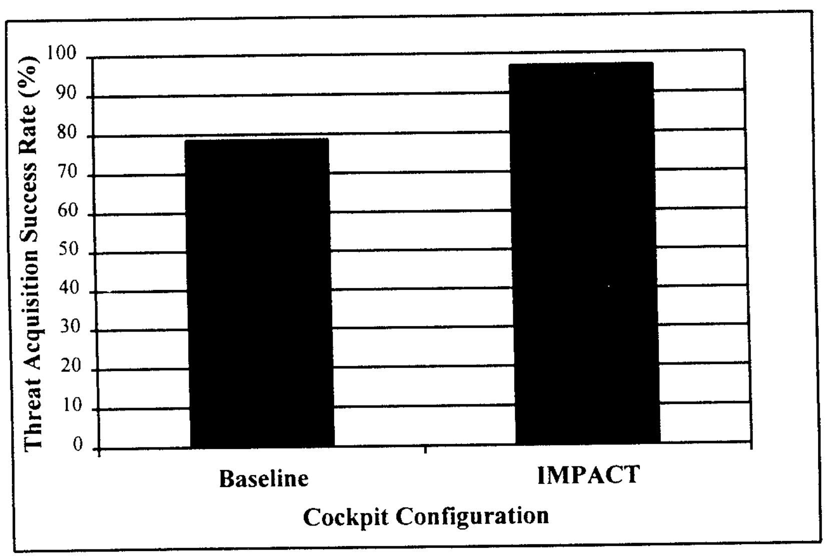

Figure 9. Mean Threat Acquisition Success Rate

A significant main effect for Threat Difficulty was found as a function of the threat acquisition success rate. The success rate was significantly higher for easy threats (91.60%) than for hard threats (83.91%).

4.2 Measures of Workload

A 2 x 2 (Cockpit Configuration by Threat Difficulty) repeated measures ANOVA was performed on the SWAT data. The SWAT scores were significantly lower for the IMPACT cockpit than for the baseline in both the easy and hard threat conditions (see Figure 10).

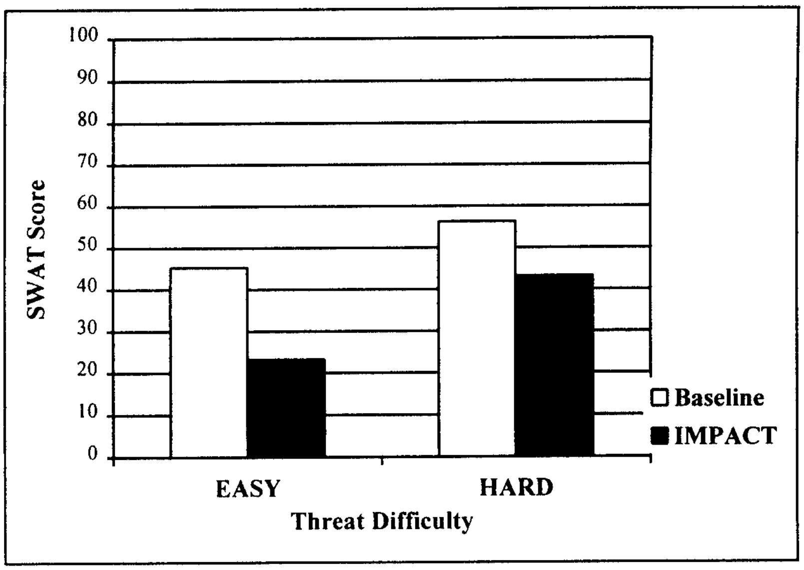

Figure 10. Mean SWAT Scores

A significant main effect for Cockpit Configuration was found as a function of SWAT scores. Workload was significantly lower for the IMPACT cockpit (Mean SWAT score = 33.20) than for the baseline (Mean SWAT score = 50.78).

A significant main effect for Threat Difficulty was found as a function of SWAT scores. SWAT scores were significantly lower for easy threats (Mean SWAT score = 34.23) versus hard threats (Mean SWAT score = 49.75).

For the Weapon Delivery Phase, a separate 2 x 2 (Cockpit Configuration by Target Difficulty) repeated measures ANOVA was performed on the SWAT data. No significant differences were found in SWAT scores regarding Target Difficulty or Cockpit Configuration.

4.3 Measures of Situation Awareness

A Subjective WORkload Dominance (SWORD) form was given to the pilots to evaluate situation awareness for the Mission Functions. Mission Functions included threat acquisition, target acquisition, and fly/navigate. A 2 x 3 (Cockpit Configuration by Mission Function) repeated measures ANOVA was performed on the SWORD data and the results are shown in Figure 11.

A significant Cockpit Configuration by Mission Function interaction was discovered. SA was rated higher for the IMPACT cockpit than for the baseline during the Threat Acquisition and Target Acquisition functions. There was no statistically significant difference between cockpits for SA during the Fly/Navigate function.

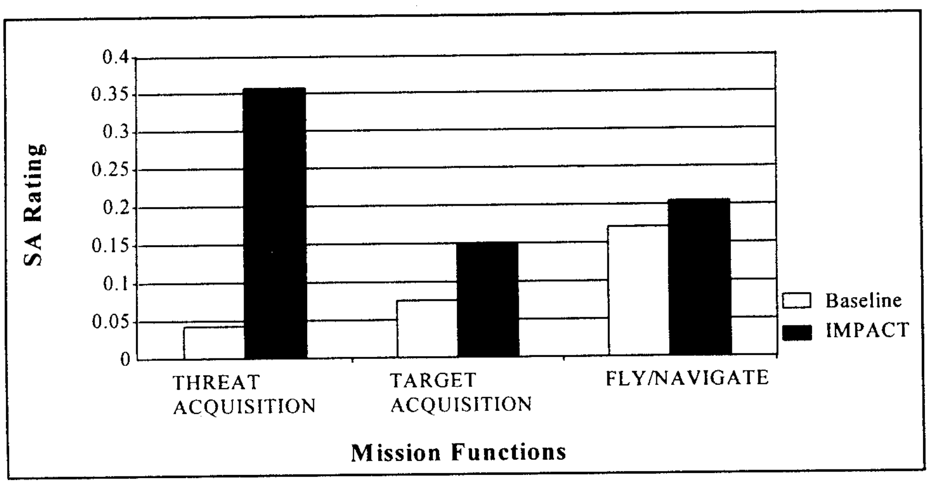

Figure 11. Mean SWORD Situation Awareness Ratings

4.4 Measures of Performance

Flight performance parameters, such as altitude, heading, and airspeed were collected and analyzed for the threat acquisition and weapon delivery functions. Deviations from the planned

altitude, heading, and airspeed were analyzed for each Cockpit Configuration and Threat Difficulty level.

4.4.1 Flight Performance During Threat Acquisition

All flight path tracking analyses were conducted using a 2 x 2 (Cockpit Configuration by Threat Difficulty) repeated measures ANOVA. Separate analyses were conducted based on the Mission Phase (Medium Altitude Cruise, TFR Descent, and TFR Ingress) because each phase had different MOPs and different criteria. Data collected only during threat engagements were analyzed.

During threat acquisition, deviations from planned altitude, course, and groundspeed were analyzed. A significant Configuration by Threat Difficulty interaction was found. Altitude deviation was significantly lower for the IMPACT cockpit (107.95 ft.) compared to the baseline (285.68 ft.) in the easy threat condition. No significant effects were found between the IMPACT cockpit and the baseline in the hard threat condition.

A significant main effect for Cockpit Configuration as a function of course deviation was found. Regardless of threat difficulty, pilots maintained course significantly better with the IMPACT cockpit versus the baseline cockpit (see Figure 12).

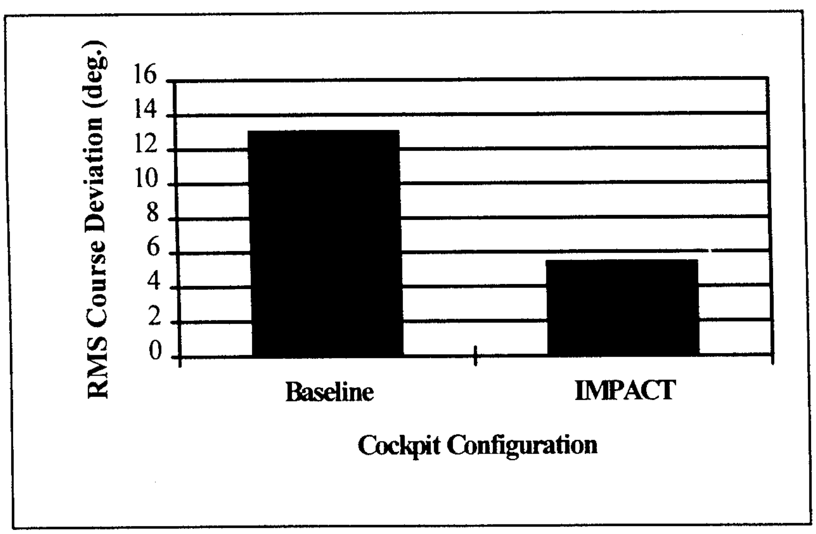

Figure 12. Mean RMS Course Deviation During Medium Altitude Cruise

Finally, for groundspeed, no significant differences were found between the cockpit configurations.

Significant main effects were found, however, for Threat Difficulty as a function of both course deviation and groundspeed deviation. Smaller course deviations were found in the easy threat condition (6.85°) than in the hard threat condition (11.58°). Smaller groundspeed deviations were found in the easy threat condition (18.50 kts.) than in the hard threat condition (49.99 kts.). No other interaction or main effects were discovered.

Deviation from planned dive angle was analyzed in the TFR Descent Phase. No interaction effects or main effects were found.

Deviations from planned course, groundspeed, and terrain following were analyzed in the TFR Ingress Phase. Significant main effects for Cockpit Configuration were found for course deviation and TFR deviation with the IMPACT cockpit demonstrating significantly less deviations compared to the baseline. No significant differences were found between cockpit configurations for groundspeed deviation. Significant main effects were also found for Threat Difficulty as a function of course deviation, groundspeed deviation, and TFR deviation with easy threats resulting in smaller deviations than hard threats.

4.4.2 Flight Performance During Weapon Delivery

Weapon Delivery analysis was conducted using a 2 x 2 (Cockpit Configuration by Target Difficulty) repeated measures ANOVA. Deviations from planned vertical flight, attack course, and groundspeed were analyzed in this phase.

A significant main effect for Target Difficulty was found only for vertical flight deviation. The pilots had significantly less vertical flight deviation in the easy target condition (315.42 ft.) than in the hard target condition (503.28 ft.). No other main effects or interactions were found for attack course deviation or groundspeed deviation. In addition, no significant differences were found between cockpit configurations for any of the flight performance variables.

4.5 Subjective Data

Frequencies and mean ratings were calculated for all questionnaire items. Complete responses to open-ended questions and other pilot comments are included in Appendix E. Both post-mission and post-experiment questionnaires were used to address the overall contributions of each technology and the specific individual contributions of each technology element.

4.5.1 Threat Acquisition Effectiveness

The pilots rated threat acquisition easier in the IMPACT cockpit than in the baseline.

Because of the HMD threat cueing capability, 16 out of 18 pilots specifically commented that IMPACT was a vast improvement over the baseline for threat acquisition. Conversely, six out of 18 pilots commented that threat acquisition in the baseline was more difficult, mainly due to the lack of threat elevation cueing.

Threat acquisition was composed of three elements: determining azimuth, determining elevation, and determining range. Figure 13 shows pilot ratings for the overall cockpit effectiveness for each of these tasks.

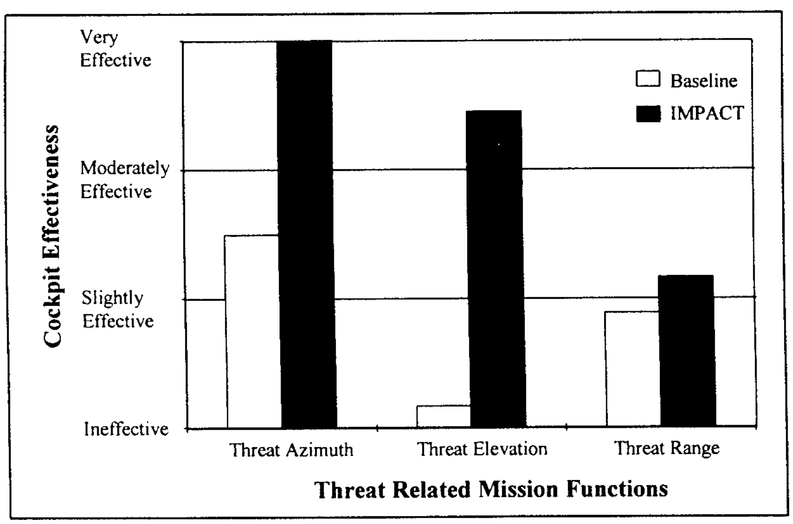

Figure 13. Average Cockpit Effectiveness Ratings for Determining Threat Location

The pilots were also asked to assess the contributions of each technology to the threat acquisition elements (azimuth, elevation, range). According to their responses, Figure 14 shows

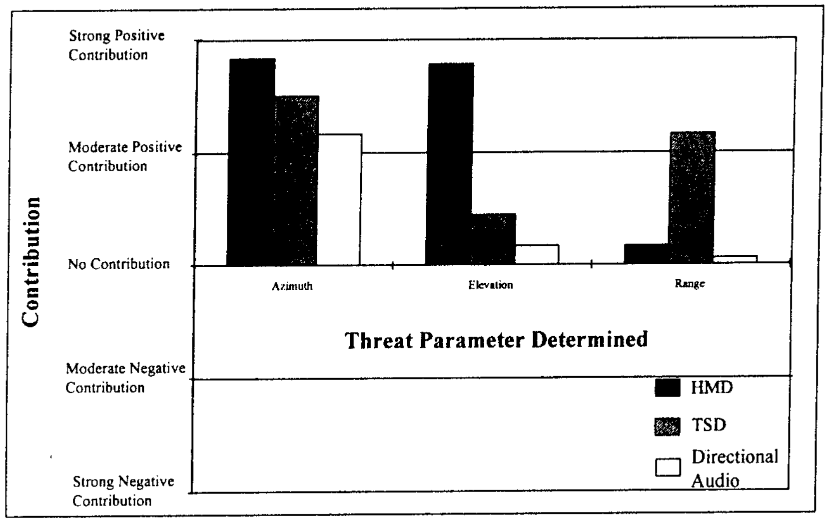

Figure 14. Contributions of Technologies to Threat Localization

that the strongest contribution of the HMD was in its ability to aid the pilot in determining threat azimuth and elevation. The TSD made its greatest contributions in aiding threat azimuth and range determination, and directional audio made a moderate contribution in threat azimuth determination.

4.5.2 Weapon Delivery Effectiveness

Target Acquisition was rated slightly easier in IMPACT than in the baseline cockpit. The following pilot comment provides a possible reason why this rating was given: "I used (the) helmet to see when to roll out . . . (I) had more time than I would have had otherwise." Figure 15 depicts cockpit effectiveness for the Target Acquisition and Weapon Delivery functions. The IMPACT configuration was rated more effective than the baseline for the Target Location and Weapons Delivery functions.

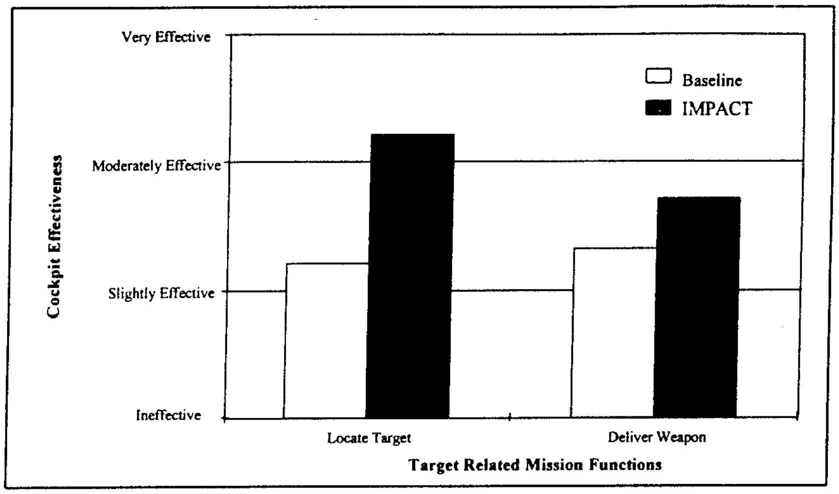

Figure 15. Average Cockpit Effectiveness Ratings for Locating Target and Delivering Weapon

4.5.3 Aircraft Control

The pilots were asked to assess the cockpits for flying difficulty. They reported that they found both cockpits moderately easy to fly, with IMPACT being slightly easier.

When the pilots were asked for cockpit effectiveness ratings on the post-experiment questionnaire, they rated the IMPACT cockpit slightly more effective than the baseline. Figure 16 shows the results.

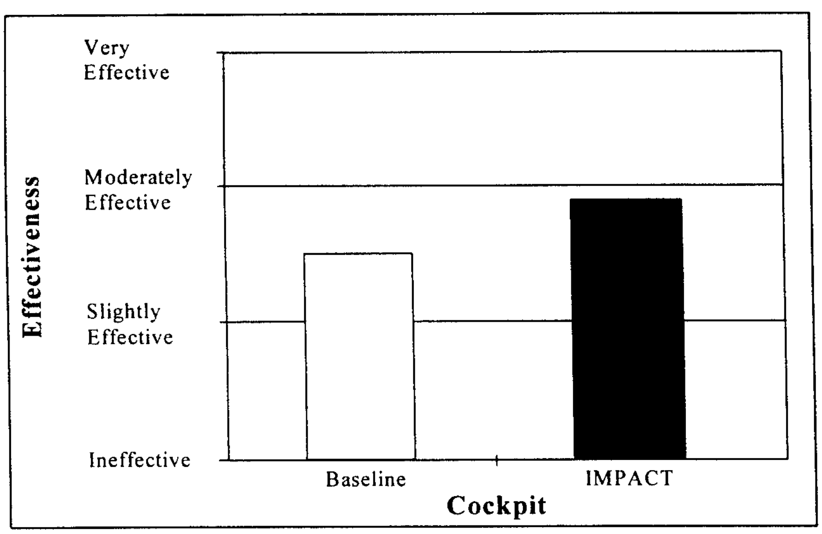

Figure 16. Average Cockpit Effectiveness Ratings (Flying)

The contributions of the three advanced technologies to situation awareness are shown in Figure 17, with the TSD making the largest contribution. Six out of 18 pilots specifically identified the IMPACT TSD as providing the greatest level of situation awareness.

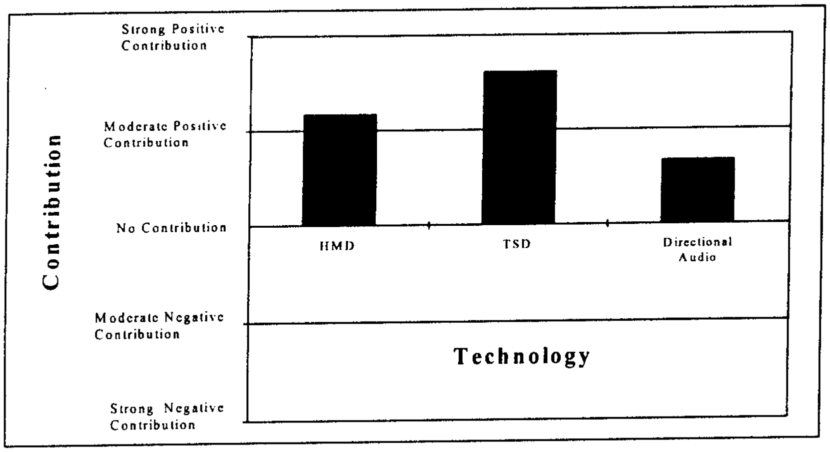

Figure 17. Contributions of Technologies to Maintaining Situation Awareness

4.5.4 Hardware and Design Characteristics

The design characteristics of the three advanced technologies were examined to determine pilot acceptance. Figure 18 shows the acceptability ratings. The TSD was the closest of the three to being rated "completely acceptable", with the directional audio rated "moderately acceptable". Some pilots stated that the TSD was better than a wingman for conveying whether they are being targeted by a threat, and one said that it was "...the best SA device ever."

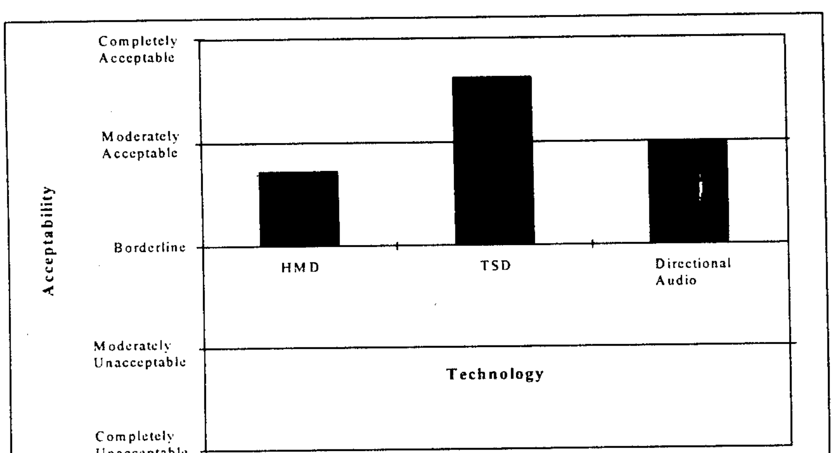

Figure 18. Average Acceptability Ratings of Design Characteristics

5. DISCUSSION

In this section, the effects of the experimental results and their relationships to the following four objectives are addressed: threat acquisition performance, pilot flight performance during weapon delivery, pilot workload and situation awareness, and the strengths and weaknesses of the cockpit mechanization.

5.1 Threat Acquisition Performance

The first objective of this experiment was to evaluate threat acquisition performance in both the baseline cockpit and the IMPACT cockpit configuration. Specific points of interest were the threat acquisition time and the threat acquisition success rate. Statistical analysis showed that overall, the IMPACT cockpit elicited significantly faster acquisition times and higher success rates than the baseline. The large TSD, the HMD, and directional audio gave the pilot a more detailed depiction of threat location. These technologies allowed the pilot to acquire the threat quicker and with less aircraft maneuvering, which resulted in a higher success rate, significantly lower workload, and better SA.

Regarding threat acquisition, the pilots greatly favored the implementation of the HMD. Threat cueing symbology was rated particularly high for determining threat azimuth and elevation. The TSD was given high acceptability ratings and provided the pilot with additional threat range information as well as awareness of threat type (air-to-air or air-to-ground). Finally, several of the pilots commented favorably concerning the directional audio technology. Even though it received the lowest rating of all the advanced technologies studied, directional audio appeared to provide initial threat azimuth information to the pilots who used it. Implementation of a true 3-D audio system may provide more compelling results.

5.2 Flight Performance During Threat Acquisition

Associated with the assessment of threat acquisition time (the primary objective of this experiment) was the evaluation of flight performance during threat acquisition. In the IMPACT cockpit, the pilots were significantly more precise in maintaining the specified course and terrain

following parameters while acquiring threats. This improvement in performance was true regardless of threat difficulty and was most likely due to the tendency of the pilots to maneuver the IMPACT cockpit less than the baseline (because of the additional cueing capability in the IMPACT configuration). When flying the baseline cockpit, pilots recognized the system limitations and were very methodical in locating threats. They typically maneuvered to place the threats in their 3 or 9 o'clock position (resulting in large course deviations), rolled the aircraft wings level, and then began to search for the threat in elevation.

One concern is the major deviations in altitude and groundspeed that were observed with the IMPACT cockpit during the Medium Altitude Cruise Phase. Although not statistically significant, preliminary evidence may exist that could indicate a degradation of cockpit cross-checking during a high threat situation at medium to high altitudes. One cause may be the added capability of the HMD, allowing the pilot to immediately go "heads-up" using the cueing symbology to locate threats. Naturally, the more time it takes to locate a threat, the less time the pilot spends "heads-down" while cross-checking the instruments. Therefore, additional HMD flight symbology or training may be necessary to diminish the possibility of pilots losing awareness of the aircraft attitude.

5.3 Flight Performance During Weapon Delivery

The second objective of this experiment was to evaluate the pilots' flight performance while attacking ground targets. Contrary to the team's hypothesis, the IMPACT configuration showed no improvement over the baseline for weapon delivery. Even though the expanded TSD and the target locator line provided in the HMD promoted easier target acquisition with IMPACT, which is supported by post-mission ratings provided by the pilots, flight performance during the Weapon Delivery Phase was consistent across both configurations.

The lack of statistically significant results during weapon delivery may be attributed to the difficulty of the maneuver. When a pilot is trained to fly fighter aircraft, pop-up weapons deliveries are among the last to be taught. These maneuvers are normally accomplished only in the daytime. Although, some F-15E and F-16 pilots are certified to accomplish this at night

using the LANTIRN system, they only attack targets that are within the LANTIRN FOV during the maneuver. The inherent difficulty of the maneuver combined with trying to accomplish it in a simulator without the cues normally associated with flying an aircraft (e.g., g-forces and vibrations) made this task very challenging. Simulation tests were conducted to determine if advanced technologies could better support the pilot in performing such maneuvers. However, once the pop-up maneuver was initiated in the advanced configuration, pilots seemed to concentrate on the HUD. The HUD format was the same for both the baseline and IMPACT configurations, which probably negated potential differences.

Even though considerable training was conducted in the use of the HMD during roll-in, some of the pilots' comments indicated they did not begin to exploit the capability until later data runs. More extensive training (not possible under the time constraints of this experiment) may have resulted in more effective use of the HMD symbology for this task. Another factor that could have affected results was the lack of a smooth transition of the target designator diamond from the HMD to the HUD. With a "seamless" transition of the target diamond (as would be possible with an HMD-projected "virtual" HUD) a more intuitive use of the symbology could result.

5.4 Pilot Workload and Situation Awareness

The third objective of this experiment was to evaluate pilot workload and SA in both the IMPACT and baseline cockpits. Statistical analysis showed that the IMPACT cockpit elicited significantly lower workload than the baseline with the exception of the weapon delivery function. No significant workload differences were found during weapon delivery primarily because the inherent difficulty of the weapon delivery maneuver, combined with trying to accomplish the maneuver in a simulator without the cues normally associated with flying an aircraft (e.g., g-forces and vibrations) made this task very challenging. Once the pop-up maneuver was initiated in the advanced configuration, pilots seemed to concentrate on the HUD, and because the HUD format was the same for both the baseline and IMPACT configurations, potential workload differences were minimized.

Statistical analysis results indicated a significant increase in SA with the IMPACT cockpit relative to the baseline (with the only exception being navigation). Factors contributing to this result can be attributed to the added threat location capabilities provided by IMPACT's advanced technologies. Specifically, pilots found it easier to acquire threats using the HMD and TSD cueing symbology, and these technologies appear to be the main cause of the decrease in workload. According to pilot comments the main contributors to increased SA were the larger, more precise TSD range scale, the threat/target symbology, and navigation symbology.

5.5 Cockpit Mechanization

The forth objective of this experiment was to identify relative strengths and weaknesses of the IMPACT technologies. Overall, the pilots rated them very highly, with the large TSD rated the highest. Concerns regarding the HMD centered more around the hardware than the display design. Since this HMD was a prototype system, the helmet was not as comfortable nor was it as adjustable as it would be in an operational environment. Image quality was another issue raising concern. In fact, before the HMD could be used in an operational environment, several issues would have to be addressed, including: helmet center-of-gravity (because of the added weight of the display combiners), CRT alignment, focus, brightness under field conditions, suitable adjustment devices that provide sufficient setting feedback, fine-tuning capabilities, and ease of use on the ground and during flight.

The only major HMD symbology design concern raised by the pilots was the conflict between the threat locator line and the horizon line. These two solid lines would overlap if the threat was located at the same altitude as the aircraft. This issue will require further study, but may become less apparent in a fully dynamic threat environment (threats were simulated in fixed locations for this experiment).

The TSD was the most conventional of the three advanced technologies and, as such, was well received by the pilots. Suggested improvements focused on the separation of information. During several threat engagements, threat symbology overlapped with navigation symbology

making both sets difficult to read. Better prioritization of displayed information should remedy this problem.

Finally, directional audio capabilities must continue to be developed and evaluated to obtain a more accurate depiction of its potential contribution.

6. CONCLUSIONS

This experiment was successful in evaluating three specific advanced technologies: HMD, large TSD, and directional audio. The integration of these technologies into the IMPACT cockpit provided significant benefits over the baseline configuration. With regard to threat acquisition, pilots were successful in performing functions that are currently augmented by the WSO without increasing workload or decreasing situation awareness. Continued effort is required, both in the development of technology and simulation capability, to obtain a more accurate indication of performance concerning weapon delivery in the IMPACT cockpit. These efforts are very important steps in developing a single-seat, multi-role fighter aircraft required to perform precision attack at night and in adverse weather.

Further development of the HMD, large TSD, and directional audio, as well as the integration of other advanced technologies, are the objectives of future IMPACT experiments.

7. RECOMMENDATIONS

Further development of the HMD, TSD, directional audio, and additional integration of advanced target detection and designation technologies is necessary to accomplish the goal of defining single-seat, multi-role fighter cockpit design requirements.

- **HMD**

Specifically, HMD symbology requires evaluation under dynamic threat conditions. Additional symbology may be necessary for pilots to control the aircraft more effectively while directing attention outside the aircraft. This is especially true during manual terrain following conditions. Also, more HMD capability must be integrated for weapon delivery functions.

- **TSD**

Refinement of the TSD is necessary to prioritize information. For example, threat information should take precedence over navigation information unless otherwise requested by the pilot. This type of information prioritization would reduce display clutter.

- **Audio**

Additional hardware capabilities are required to properly implement 3-D audio technology. Further evaluation is necessary under more realistic operational environments to completely understand and utilize the potential benefits of advanced audio displays.

Finally, further evaluation of advanced technologies is required to determine their effects on pilot workload and SA in the absence of the WSO. Specifically, additional research is necessary to measure the ability of a single pilot, with the support of advanced technologies, to execute functions currently performed by the WSO during the weapon delivery phase of an interdiction mission. These functions include controlling the air-to-ground radar and patch map designation of ground targets.

8. REFERENCES

Barnes, W. J. (1989). Tactical Applications of the Helmet Display in Fighter Aircraft. SPIE, Vol. 1116, 149-160. Tucson, Arizona: Air National Guard Air Force Reserve Test Center.

Dawson, G. C., Spengler, R. P., Moreland, H. H., Turner, L. W., Schiavone, A. J., and Hanson, R. F. (1993). Mission Reconfigurable Cockpit (MRC), Human Engineering Progress Report: Volume 1. Technical Report, WL-TR-94-3010, Wright-Patterson Air Force Base, Ohio: Wright Laboratory.

Dolan, N. J., Wells, M. J., and Osgood, R. K. (1993). A Comparison of Performance with Visual and Localized Auditory Displays in a Simulated Target Localization Task. In R. S. Jensen (Ed.), Seventh International Symposium On Aviation Psychology, 49-53. Columbus, Ohio: Ohio State University.

Galvin, T., and Pecha P. (1992). Joint Tactical Information Distribution System: F-15 C/D MSIP Full Scale Development. McDonnell Aircraft Company. St. Louis, Missouri.

Lee, M. D., Patterson, R. W., Folds, D. J., and Dotson, D. A. (1993). Application of Simulated Three-Dimensional Audio Displays to Fighter Cockpits: A User Survey. IEEE, 654-660.

Montecalvo, A. J., Redden, M. C., Rolek, E. P., Orr, H. A., and Barbato G. J. (1994). Integrated Mission/Precision Attack Cockpit Technology (IMPACT). Phase 1: Identifying Technologies for Air-To-Ground Fighter Integration. Technical Report, WL-TR-94-3143, Wright-Patterson Air Force Base, Ohio: Wright Laboratory.

Reid, G. B., Potter, S. S., and Bressler, J. R. (1989). Subjective Workload Assessment Technique (SWAT): A User's Guide. Technical Report, AAMRL-TR-89-023, Wright-Patterson Air Force Base, Ohio: Armstrong Aerospace Medical Research Laboratory.

Royer, R. R., (1991). Night Attack Program Pilot-Vehicle Interface Study. Final Report, F33657-84-C-0247, General Dynamics, Fort Worth TX.

Royer, R. R., (1992). Night Attack Program Pilot-Vehicle Interface Study: Block 30 CAS/BAI Retrofit. Final Report, General Dynamics, Fort Worth TX.

TO 1F-15E-1. Flight Manual. USAF Series F-15E Aircraft. McDonnell Douglas Aerospace, D 15 April 1993.

TO 1F-15E-34-1-1. Nonnuclear Weapon Delivery Manual. USAF Series F-15E Aircraft. McDonnell Douglas Aerospace, C 15 Sept. 1991.

Vanderbach, H. W., Patzek, M. J., Barbato, G. J., McCracken, J. R., and Lutz, H. L. (1993). Tactical Aircraft Cockpit Study (TACS): Integrated Control and Avionics for Air Superiority (ICAAS) Support. Technical Report, WL-TR-93-3076, Wright-Patterson Air Force Base, Ohio: Wright Laboratory.

Vidulich, M. A. (1989). The Use of Judgment Matrices in Subjective Workload Assessment. The Subjective Workload Dominance (SWORD) Technique. Proceedings of Human Factors Society 33rd Annual Meeting, Vol. 2, (pp. 1406 - 1410). Santa Monica, CA: Human Factors Society.

Way, T. C., Martin, R. L., Gilmour, J. D., Hornsby M. E., and Edwards R. E. (1987). Multi-Crew Pictorial Format Display Evaluation. Technical Report, AFWAL-TR-87-3047, Wright-Patterson Air Force Base, Ohio: Air Force Wright Aeronautical Laboratories.

Wickens, C. D., Sandry, D., and Vidulich, M. (1983). Compatibility and Resource Competition Between Modalities of Input, Central Processing, and Output: Testing a Model of Complex Task Performance. Human Factors, 25, 227-248.

APPENDIX A

SIMULATION PROJECT MODIFICATION REQUESTS (SPMRs)

INTRODUCTION

These Simulation Project Modification Requests (SPMRs) define the simulator configuration used in IMPACT Advanced Technology Experiment # 2. The SPMRs are grouped into three sections:

- Baseline Cockpit Requirements
- IMPACT Cockpit Requirements
- Common Simulation Requirements

Throughout the SPMRs (Appendix A), Questionnaires and Data Collection Forms (Appendix C), and Experimental Design (Appendix D) all references to the "F-15E" have been changed to the "Baseline" cockpit. This reduces potential confusion that the Baseline cockpit simulated in the experiment, which had the F-15E as its "model", had the same level of functionality as a high-fidelity F-15E simulation.

The SPMRs describe the control and display configurations that were originally envisioned for the baseline and IMPACT cockpits. Numerous modifications were made to the controls and displays while refining the experimental test plan, implementing the designs, and performing pre-experimental checkouts prior to the study.

Several controls and displays developed for the IMPACT Program were not implemented in this experiment, and are annotated in the SPMR Table of Contents accordingly.

To document the changes and record the design team's rationale for the changes, a REMARKS/LESSONS LEARNED section has been added to each SPMR.

TABLE OF CONTENTS

SECTION 1: BASELINE COCKPIT REQUIREMENTS

SECTION 2: IMPACT COCKPIT REQUIREMENTS

SPMR	TITLE
2.0	Cockpit Layout
2.1	IMPACT Stick and Throttles
2.2	Display Cursor Control **(not implemented for this study)**
2.3	Head-Up Display (HUD)
2.4	Up-Front Control (UFC)
2.5	Air-to-Air (A/A) Radar **(not implemented for this study)**
2.6	Air-to-Ground (A/G) Radar **(not implemented for this study)**
2.7	Sensor/AGM Video **(not implemented for this study)**
2.8	3-D Audio
2.9	Terrain-Following (TF) Radar
2.10	Tactical Situation Display (TSD)
2.11	Weapons/Countermeasures (WPNS/CM) Display
2.12	Attitude Director Indicator (ADI)
2.13	Horizontal Situation Indicator (HSI) **(not implemented for this study)**
2.14	Engine/Fuel Display
2.15	Helmet-Mounted Display (HMD)
2.16	Emergency Procedures (EP) Checklists **(not implemented for this study)**

SECTION 3: COMMON SIMULATION REQUIREMENTS

SPMR	TITLE
3.0	HUD Display on Barco Projection Screen
3.1	Forward-Looking Infra-Red (FLIR) Display
3.2	Out-the-Window Display
3.3	Feature Analysis Display
3.4	Targets
3.5	Threats

SPMR 1.0

COCKPIT LAYOUT

The baseline front cockpit was modeled after the F-15E and was characterized by three multipurpose displays (MPDs), an up-front control (UFC), and a wide field-of-view heads-up display (HUD), as shown in Figure 1.0.1. Note the numbering scheme used for the pushbuttons on the MPDs (PB 1 through PB 20, counterclockwise starting from the upper left corner).

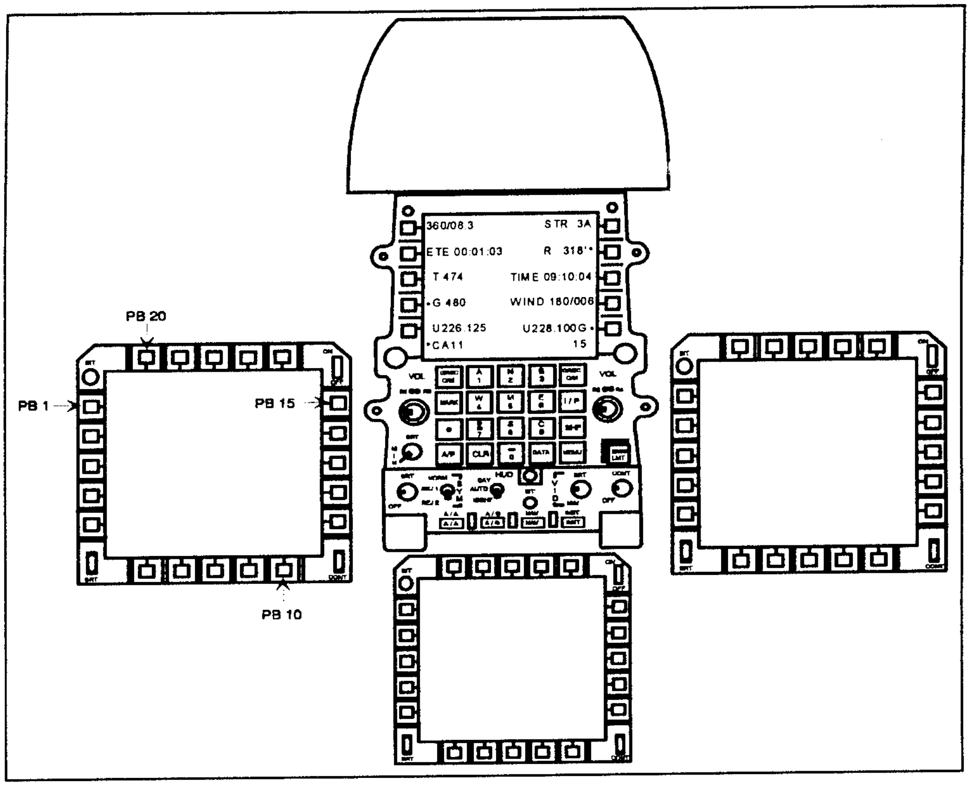

Figure 1.0.1 General Layout for the Baseline Cockpit

REMARKS/LESSONS LEARNED

The UFC and MPDs were non-interactive for Advanced Technology Experiment #1. Selected data displays were dynamic, but the pilot could not change formats, enter data, or select operating modes. The displays were presented on a large color cathode ray tube (CRT).

SPMR 1.1

BASELINE STICK AND THROTTLES

STICK

An F-15E stick grip will be used in the baseline cockpit for Advanced Technology Experiment # 2. The stick will be fully operational for control of aircraft pitch and roll. The switches on the stick grip that must function for the first demonstration are the trim switch and the castle switch. (See Figure 1.1.1). The trim switch is used for aircraft trim and countermeasures dispense, and the castle switch is used for pre-programmed display rotation.

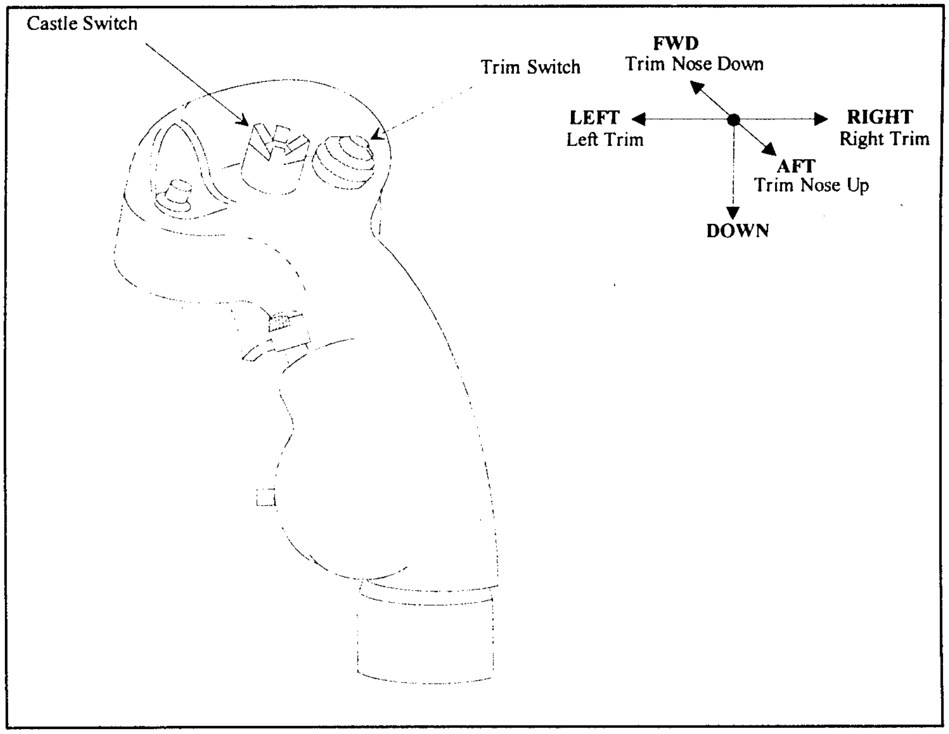

Figure 1.1.1 Baseline Control Stick

REMARKS/LESSONS LEARNED

The grip for the side-stick used in the actual simulation was slightly different from the illustration. Since the pilot was not required to change the display formats for Advanced Technology Experiment # 2, the castle switch function was not implemented. After pre-experimental sessions revealed minor problems with planned methods for countermeasures dispense function, the design team decided to use a paddle switch (not illustrated), located at the front base of the stick, to execute the function (instead of the trim switch).

THROTTLES

The throttles must be capable of controlling engine rpm, operating speedbrakes, and dispensing countermeasures.

The speedbrake switch has three positions: FORWARD, CENTER, and AFT.

- FORWARD Retracts speedbrakes
- CENTER Holds speedbrakes in current position
- AFT Extends speedbrakes

The CMD switch has two positions: UP and DOWN

- UP Manual 2 dispense
- DOWN Manual 1 dispense

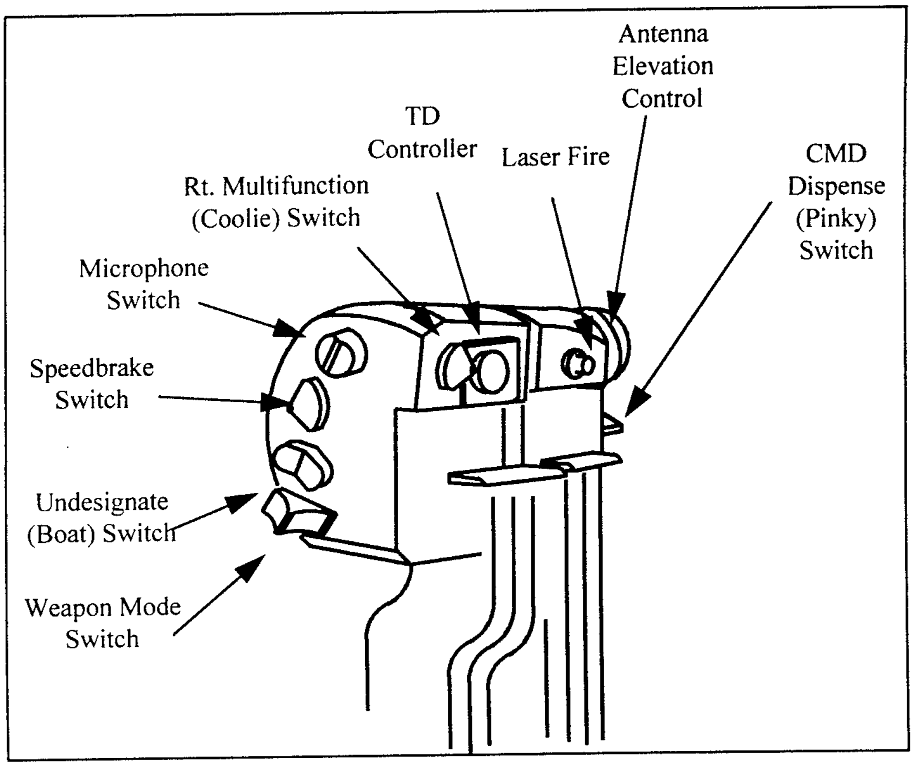

Figure 1.1.2 Baseline Throttle Switches

REMARKS/LESSONS LEARNED

The throttles in the simulator used for Advanced Technology Experiment # 2 were slightly different in configuration from the F-15E, but had functionally equivalent switches. The original plan was to use the "Pinky" switch to dispense chaff in the experiment. However, due to the somewhat awkward motion required to operate this switch and the need to obtain precise data concerning the timing of chaff dispensing, the team decided to use the paddle switch on the control stick.

SPMR 1.3

HEAD-UP DISPLAY (HUD)

INTRODUCTION

F-15E HUD symbology will be used for IMPACT Advanced Technology Experiment # 2. The symbology will include all navigation symbology, weapons delivery symbology, a manual terrain following (TF) box, radar altitude scale, and Low Altitude Navigation and Targeting Infra-Red for Night (LANTIRN) navigation pod video. The dimensions of the HUD FOV were 21° in elevation and 28° in azimuth. An example of HUD navigation symbology is shown in Figure 1.3.1.

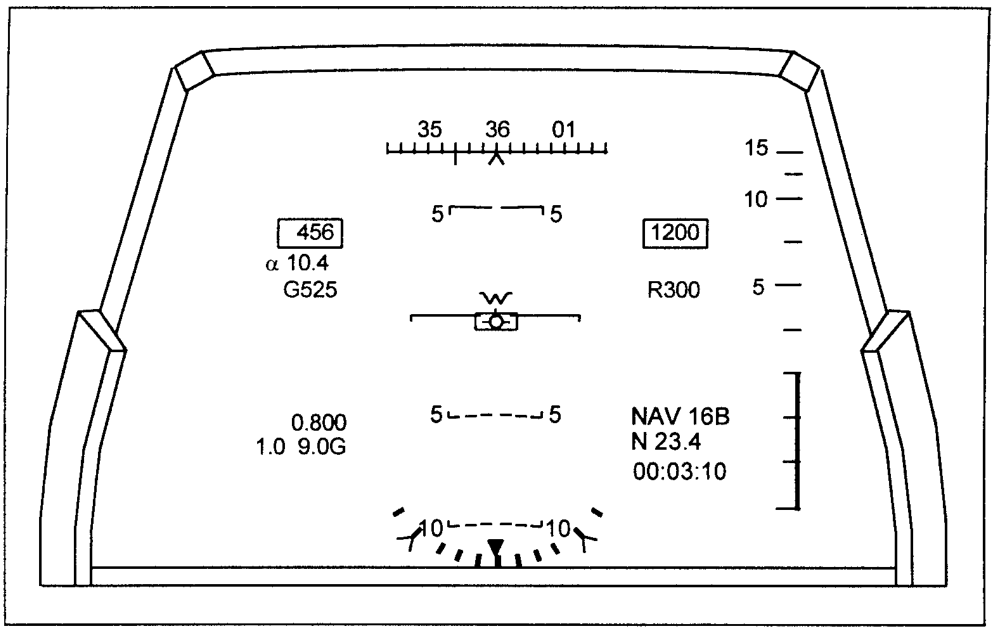

Figure 1.3.1 HUD Symbology

REMARKS/LESSONS LEARNED

The above symbology was chosen for both the baseline and the IMPACT cockpit simulations.

HUD AIR-TO-GROUND SYMBOLOGY

In the air-to-ground master mode, the manual TF box, radar altitude scale, and bank angle scale are removed from the HUD. The continuously-displayed impact point (CDIP) pipper is added as shown in Figure 1.3.2. The displayed impact line (DIL) indicates the path where the bomb will fall, and the pipper indicates the instantaneous impact point for the bomb.

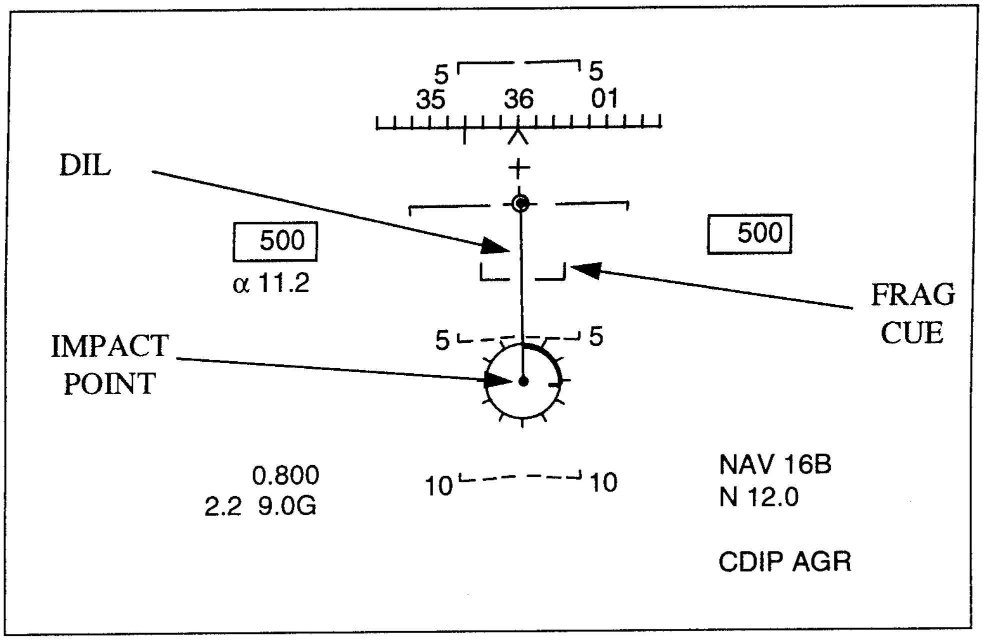

Figure 1.3.2 Air-to-Ground HUD Symbology

REMARKS/LESSONS LEARNED

The above symbology was chosen for both the baseline and the IMPACT cockpit simulations. The frag cue and the range bar shown in Figure 1.3.2 were not used in Advanced Technology Experiment # 2.

SPMR 1.4

UP-FRONT CONTROL (UFC)

INTRODUCTION

The UFC, shown in Figure 1.4.1, allows entry and readout of critical flight information. Located immediately below the HUD, it consists of a liquid crystal display (LCD) displaying speed and time, a keypad, and the HUD control panel. The keypad is used to enter data into the up-front control (UFC). Data are displayed in the scratchpad area, then entered into the system when the appropriate pushbutton (PB) is pressed. The UFC pushbuttons are numbered from one through ten, starting at the upper left corner of the UFC and moving counterclockwise around the LCD.

The master mode buttons for air-to-air, air-to-ground, navigation and instrument (A/A, A/G, NAV, and INST respectively) are "radio button" type and are located on the HUD control panel below the UFC keypad. When a master mode button is pressed, the corresponding pre-programmed displays appear on the three multi-purpose displays (MPD). In addition, the appropriate weapon delivery symbology is displayed in the HUD. The INST master mode will not be used in the IMPACT demonstrations.

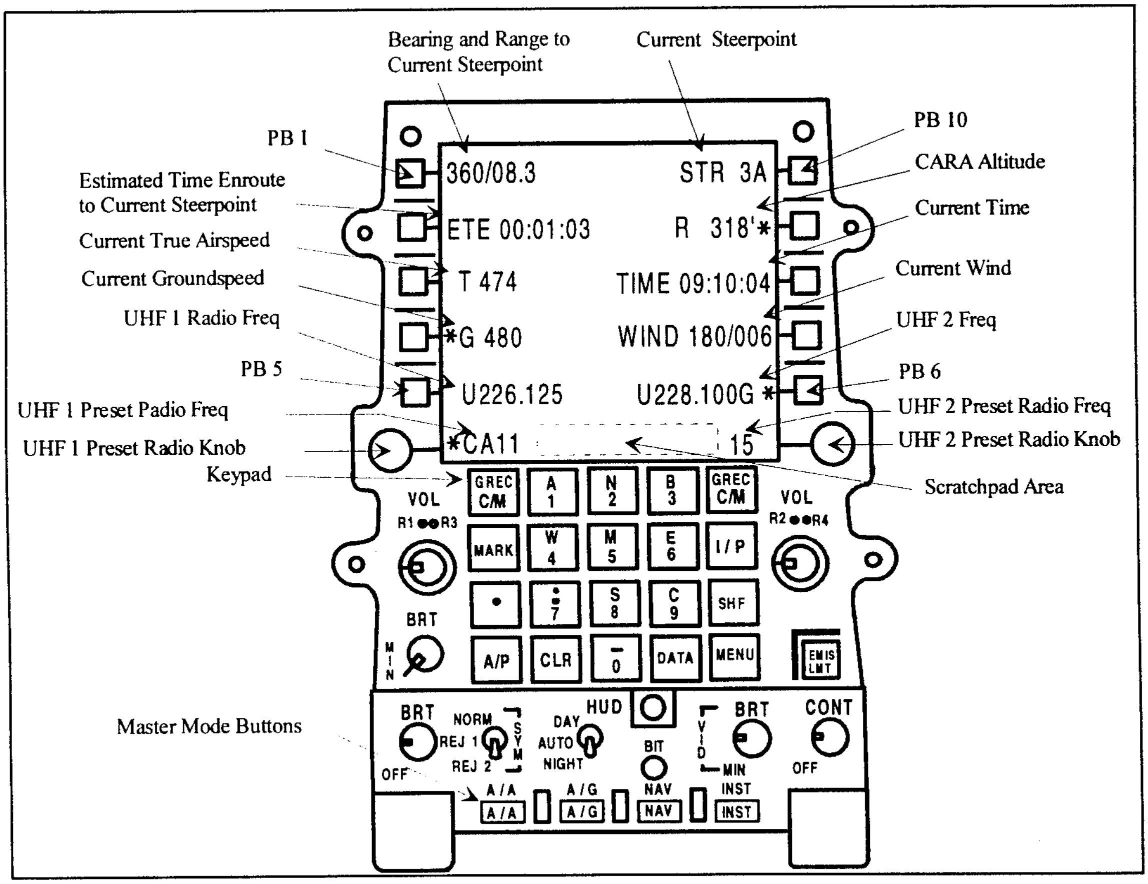

Figure 1.4.1 Up Front Control Display

STEERPOINT LATITUDE, LONGITUDE, AND ELEVATION ENTRY

To enter the coordinates and elevation of a new steerpoint, or to change those of a current steerpoint, the pilot must first go to the Point Data Lat/Long submenu as shown in Figure 1.4.2. To select a steerpoint when viewing the Data 1 display, enter the steerpoint number in the scratchpad, then press PB 10 (or PB 1 if in the Lat/Long submenu).

To enter a point's latitude and longitude, enter the hemisphere, degrees, minutes, and tenths of minutes. When the hemisphere key (N, S, E, or W) is pressed, the degree symbol, minutes symbol, decimal, and the entered letter are displayed on the scratchpad. Leading zeroes must be included if the latitude degrees are less than two digits or the longitude degrees are less than three digits. Perform the following actions from the Data 1 display:

• Select the Lat/Long submenu	Press PB 10.
• Enter the new latitude	For example, for 38 deg 45.6 north latitude, press SHF, N, 38456, then press latitude button (PB 2).
• Enter the new longitude	For example, for 90 deg 22.1 east longitude, press SHF, E, 090221, then press longitude button (PB 3).
• Enter the new elevation	Type the new elevation in the scratchpad, then press the button next to the steerpoint elevation (PB 7).
• Return to the Data 1 display	Press the DATA button on the keypad.

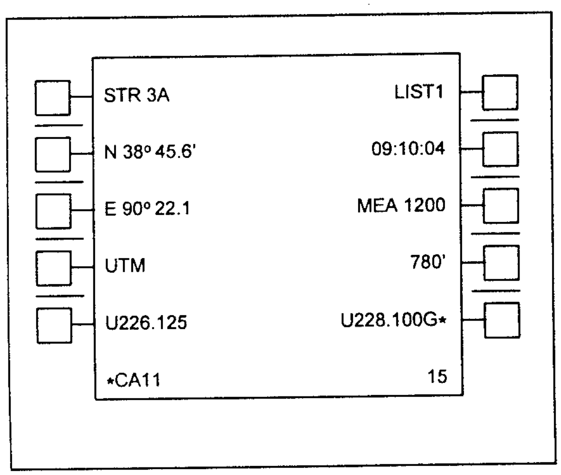

Figure 1.4.2 Up-Front Control, Lat/Long Submenu

REMARKS/LESSONS LEARNED

The UFC was implemented as a virtual display on the simulator's large color CRT for Advanced Technology Demonstration # 2. The pushbuttons were not functional, and the display was not interactive. Data 1 display was shown continuously with a combination of dynamic and static data.

SPMR 1.8

TACTICAL ELECTRONIC WARFARE SYSTEM (TEWS)

INTRODUCTION

The Tactical Electronic Warfare System (TEWS), shown in Figure 1.8.1, is composed of a compass rose that rotates as the aircraft turns, displaying current aircraft heading. Threat warning symbols are displayed at the relative bearing and approximate range from the aircraft to the threat radar. As the aircraft turns, the threat symbol maintains its position relative to the threat radar. The INS bearing pointer always points to the current steerpoint, and the bearing, range, and time to the current steerpoint are displayed in the bottom right corner of the display in the NAV data block.

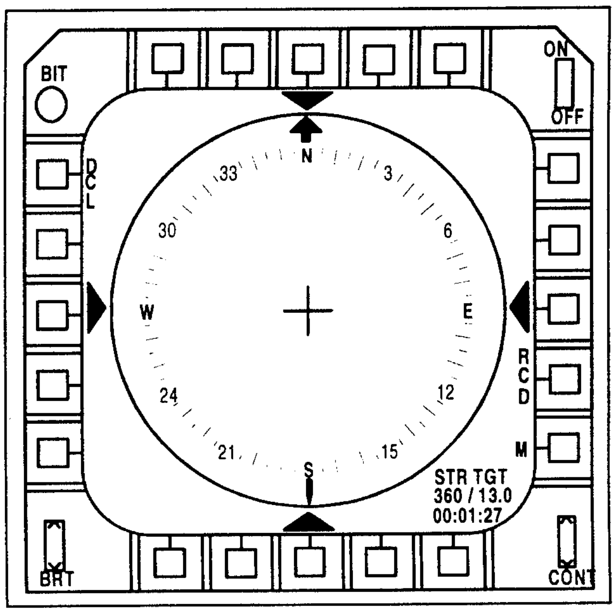

Figure 1.8.1 TEWS display

REMARKS/LESSONS LEARNED

The TEWS display was implemented in the baseline cockpit as described above.

SPMR 1.9

TERRAIN-FOLLOWING (TF) RADAR DISPLAY

INTRODUCTION

The terrain-following (TF) radar display, shown in Figure 1.9.1, will be generated based on the DTED database. A manual TF box will be displayed on this display and in the HUD for the pilot to maintain terrain clearance. The radar altitude and the aircraft groundspeed are displayed. The pilot can choose a Set Clearance Limit (SCL) by pressing the pushbutton adjacent to the desired radar altitude. This altitude is then boxed, and the manual TF box commands flight at the selected altitude.

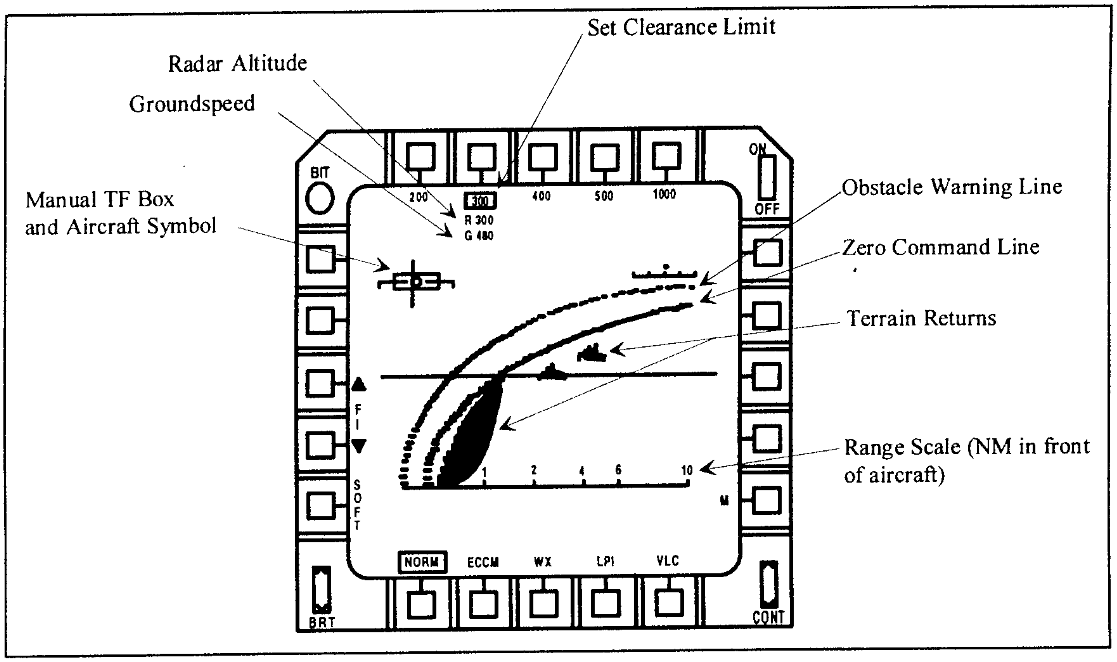

Figure 1.9.1 TF Radar Display

REMARKS/LESSONS LEARNED

The TF radar display was implemented in both the baseline (6” square format) and IMPACT cockpits (5” square format) as described above. However, because the display was simulated on a large-screen CRT, none of the MPD buttons were functional. Therefore the pilot was unable to change any of the display functions, including the set clearance limit. Aa a result, a constant 300 foot set clearance limit, with smooth ride, was selected for the scenario used in the simulation and the obstacle warning line was not implemented.

SPMR 1.10

TACTICAL SITUATION DISPLAY (TSD)

INTRODUCTION

The Tactical Situation Display (TSD), shown in Figure 1.10.1, is composed of the mission route and the steerpoint symbols displayed over a moving map (1:500,000 Tactical Pilotage Chart). The display ranges are 10, 20, 40, and 80 NM, and are selected by pressing PB 13 and 14. The steerpoint symbols are circles, and the target symbol is a triangle. Each steerpoint symbol is labeled, and the heading to the next steerpoint is displayed at the beginning of each segment. The aircraft symbol is located 1/4 of the display height from the bottom of the display when BOT is displayed at PB 6. By pressing PB 6, the aircraft symbol is placed in the center of the MPD and CTR is displayed. The pilot can choose a bank angle and airspeed to fly the mission, and the TSD will draw the route with the turn radii for that bank angle and airspeed.

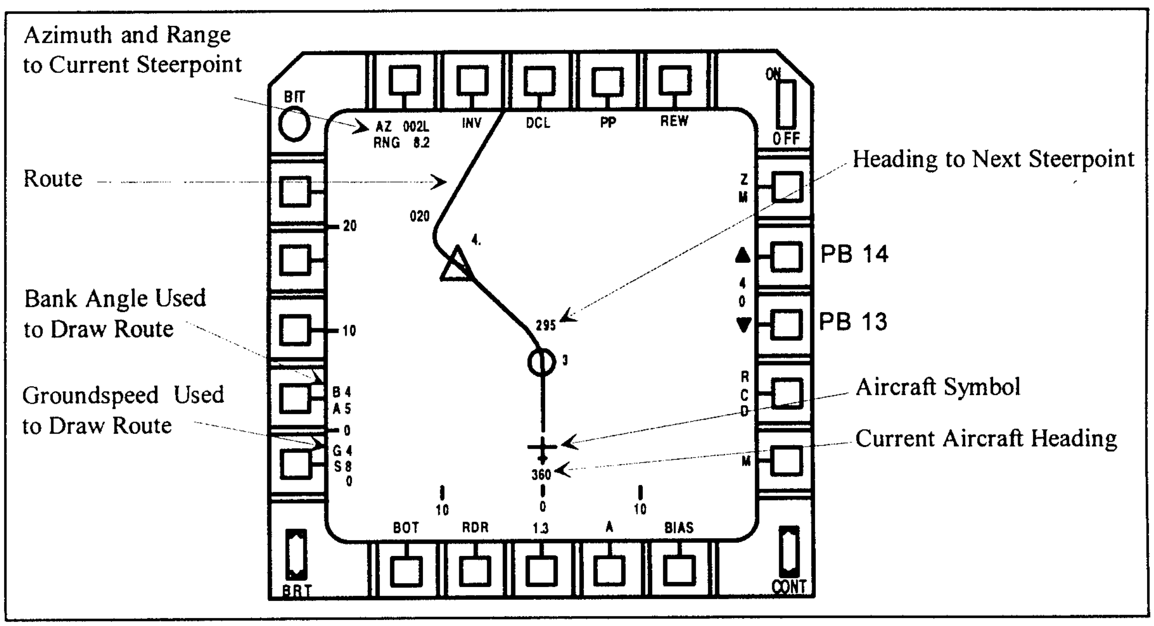

Figure 1.10.1 TSD

REMARKS/LESSONS LEARNED

The TSD was implemented as described above, with the following exceptions: Because the display was simulated on a large-screen CRT, none of the MPD buttons were functional. Therefore the pilot was unable to change any of the display functions. A fixed 20 NM range display was used, and the aircraft symbol was centered. The moving map presentation was not available, so a plain black background was used for the route depiction.

SPMR 1.12

ATTITUDE DIRECTOR INDICATOR (ADI)

INTRODUCTION

The attitude director indicator (ADI) display contains the ADI, a heading scale, a terrain following pitch steering bar, and a radar altitude scale (see Figure 1.12.1). These elements are generated by the aero model, and move in real-time as the pilot flies the aircraft. Calibrated airspeed is boxed and displayed on the left side of the ADI. The barometric altitude is boxed and displayed on the right side of the ADI, and the radar altitude is displayed below it, preceded by an "R."

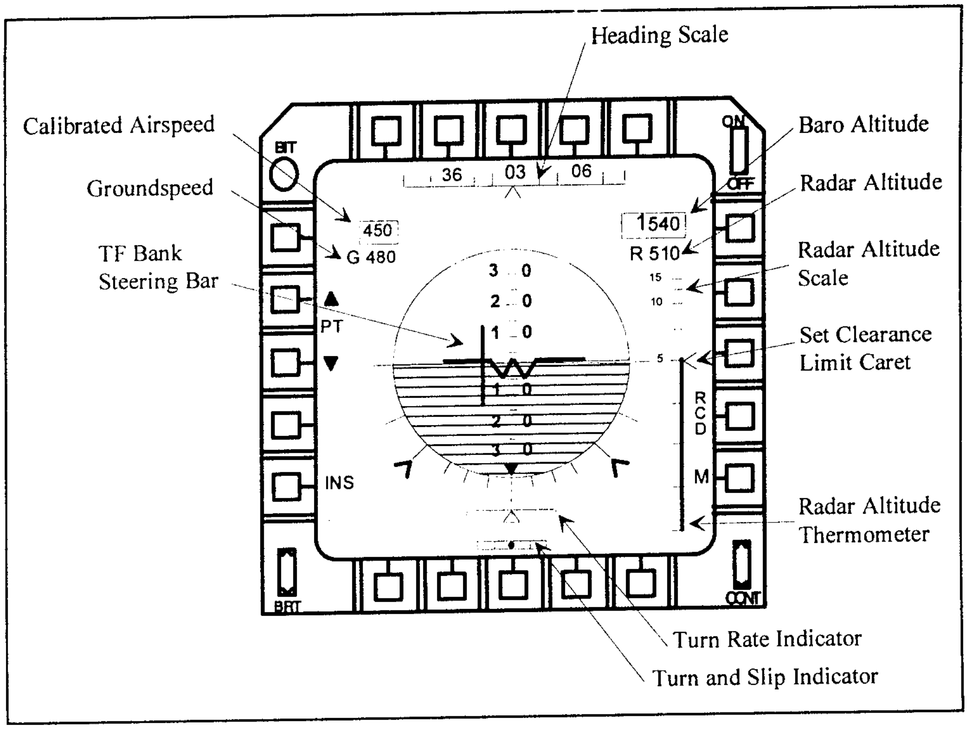

Figure 1.12.1 ADI Display

REMARKS/LESSONS LEARNED

The ADI display was presented (on the simulator's large screen CRT) in the position of the left-hand monochrome MPD. Concerns about the way the ADI ball was depicted were expressed by test subjects and members of the experiment team. In the monochrome version, the bottom of the ball was drawn with a series of closely spaced parallel (green) lines. In an unusual attitude, this was slightly misleading since the bright half of the ADI, which is normally expected to indicate the sky, indicated the ground.

SPMR 1.14

ENGINE MONITOR DISPLAY

INTRODUCTION

The engine monitor display, shown in Figure 1.14.1, contains the engine RPM, temperature, fuel flow, nozzle position, and oil pressure displayed on a single Liquid Crystal Display (LCD).

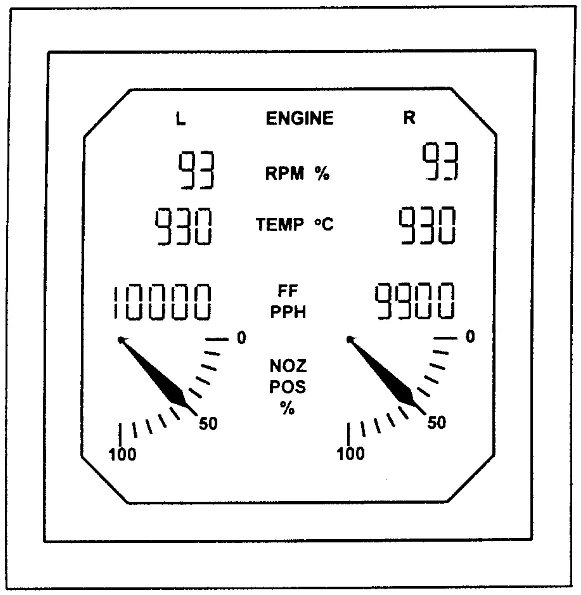

Figure 1.14.1 Engine Monitor Display

REMARKS/LESSONS LEARNED

The display was implemented as described above.

SPMR 2.0

COCKPIT LAYOUT

INTRODUCTION

The IMPACT cockpit is characterized by two 10 x 10 inch color displays. Each display can be divided into four 5 x 5 inch displays. Each 10-inch display has 40 pushbuttons (PBs), ten on each side. They are numbered from 1 to 40, starting at the upper left corner of the display and moving counterclockwise around the display, as shown in Figure 2.0.1. Possible configurations are shown in Figures 2.0.2 and 2.0.3.

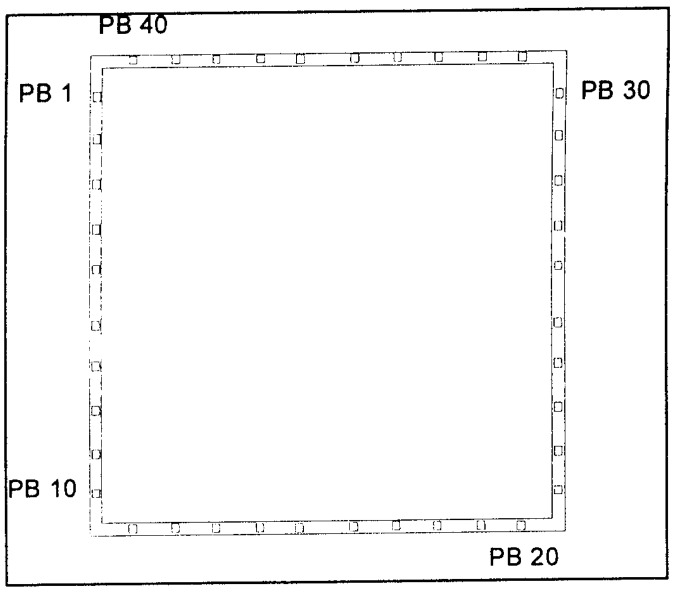

Figure 2.0.1 Pushbutton Numbering Scheme

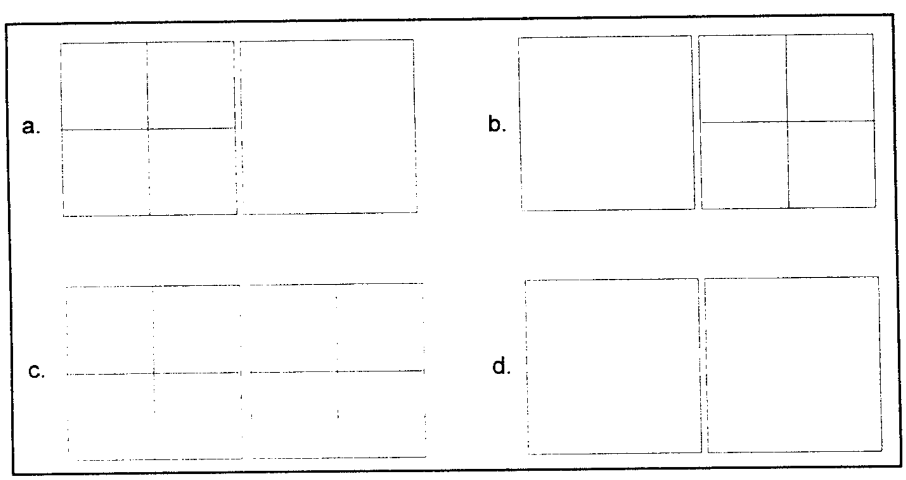

Figure 2.0.2 Possible 10 x 10 Inch Display Configurations

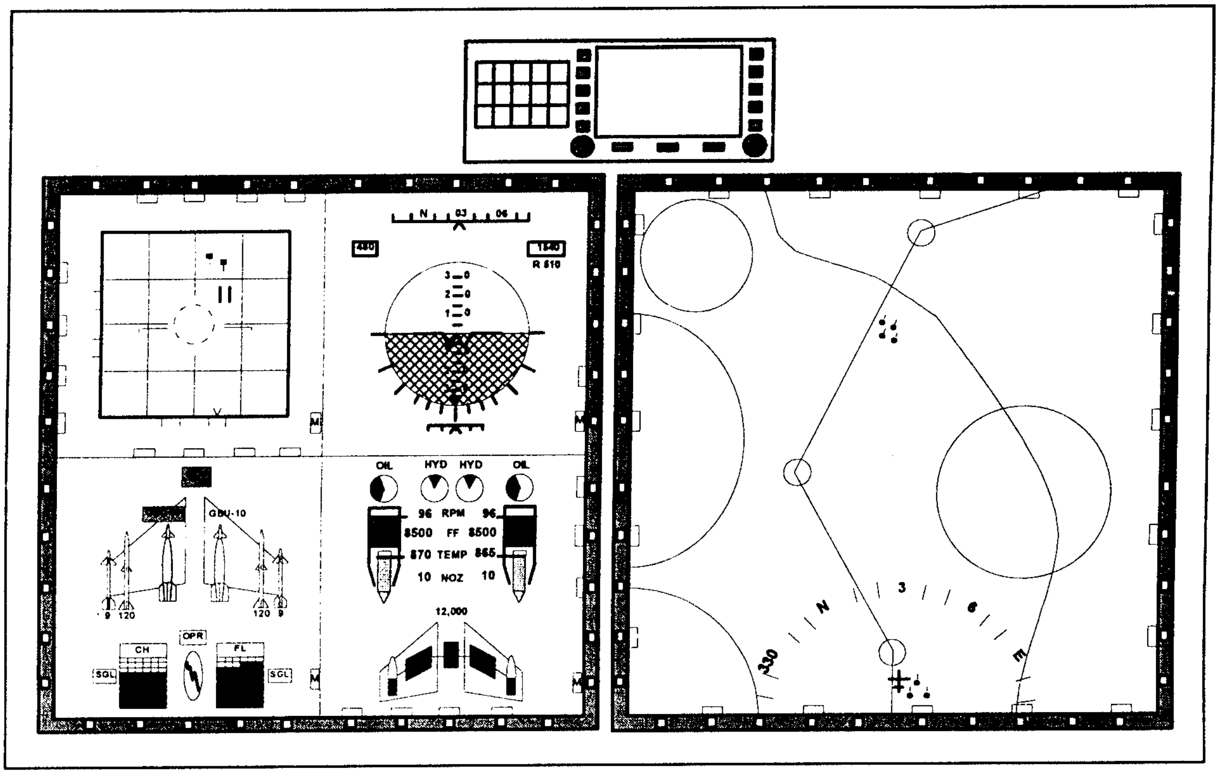

Figure 2.0.3 Possible IMPACT Cockpit Display Configuration

REMARKS/LESSONS LEARNED

A single display configuration was chosen for the IMPACT cockpit, tailored to the low-level penetration, threat evasion, and weapon delivery tasks associated with the experiment. The configuration included all the elements shown in Figure 2.0.3, except for the air-to-air display in the upper left corner. It was replaced by a terrain-following radar display, described in SPMR 2.9. The pushbuttons were not functional because the displays were simulated on a large screen CRT, and pilots were not required to change any of the displays.

SPMR 2.1

IMPACT STICK AND THROTTLES

STICK

An F-15E stick grip will be used in the IMPACT cockpit for Advanced Technology Experiment # 2. The stick will be fully operational for control of aircraft pitch and roll. The switches on the stick grip that must function for the first demonstration are the trim switch and the castle switch. The trim switch is used for aircraft trim and countermeasures dispense, and the castle switch is used for pre-programmed display rotation. (See Figure 2.1.1).

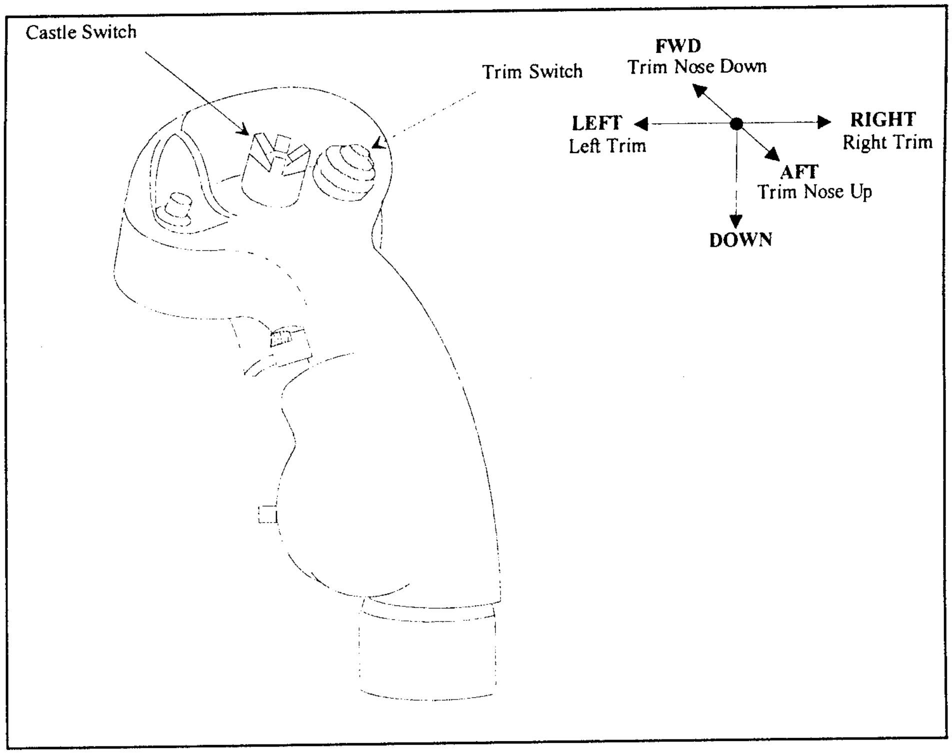

Figure 2.1.1 IMPACT Control Stick

REMARKS/LESSONS LEARNED

The grip for the side-stick used in the actual simulation was slightly different from the illustration. Because the pilot was not required to change the display formats for Advanced Technology Experiment # 2, the castle switch function was not implemented. After pre-experimental sessions revealed minor problems with planned methods for countermeasures dispense function, the design team decided to use a paddle switch (not illustrated), which was located at the front base of the stick to execute the function.

THROTTLES

The throttles used in the IMPACT cockpit are based on the F-15E throttles. They must be capable of controlling engine rpm, operating speedbrakes, and dispensing countermeasures.

The speedbrake switch has three positions: FORWARD, CENTER, and AFT.

- FORWARD   Retracts speedbrakes
- CENTER   Holds speedbrakes in current position
- AFT   Extends speedbrakes

The CMD switch has two positions: UP and DOWN

- UP   Manual 2 dispense
- DOWN   Manual 1 dispense

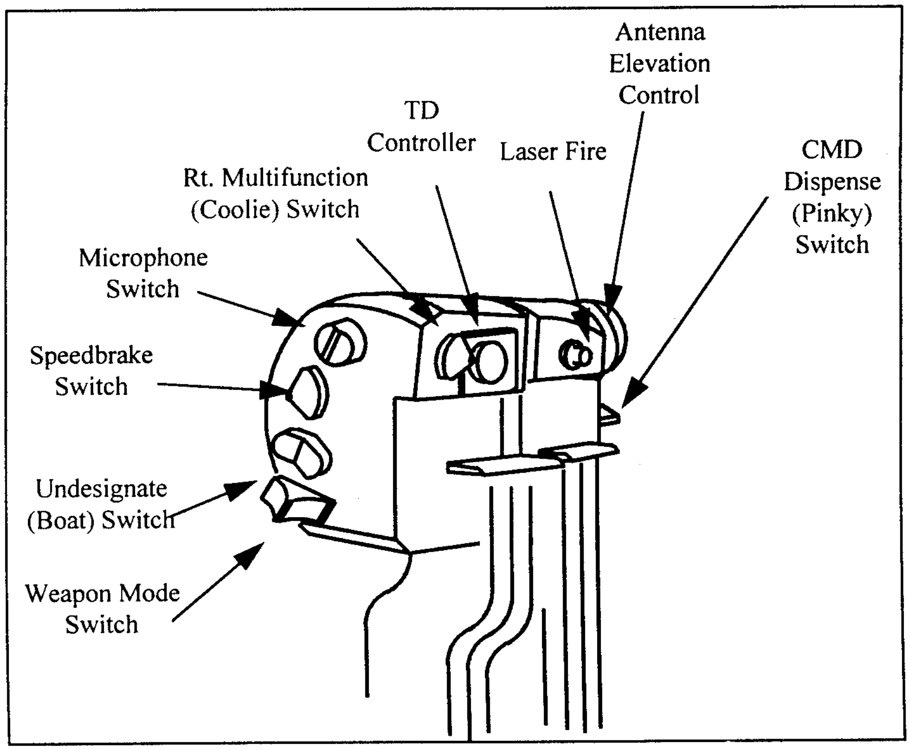

Figure 2.1.2 IMPACT Throttle Switches

REMARKS/LESSONS LEARNED

The throttles in the simulator used for Advanced Technology Experiment # 2 were slightly different in configuration from the F-15E, but had functionally equivalent switches. It was originally planned to use the "Pinky" switch to dispense chaff in the experiment. However, due to the awkward motion required to operate this switch and the need to obtain precise data concerning the timing of chaff dispensing, the team decided to use the paddle switch on the control stick instead.

SPMR 2.3

HEAD-UP DISPLAY (HUD)

INTRODUCTION

F-15E HUD symbology will be used for IMPACT Advanced Technology Experiment # 2. The symbology will include all navigation symbology, weapons delivery symbology, a manual terrain following (TF) box, radar altitude scale, and Low Altitude Navigation and Targeting Infra-Red for Night (LANTIRN) navigation pod video. The dimensions of the HUD FOV were 21° in elevation and 28° in azimuth. An example of HUD navigation symbology is shown in Figure 2.3.1.

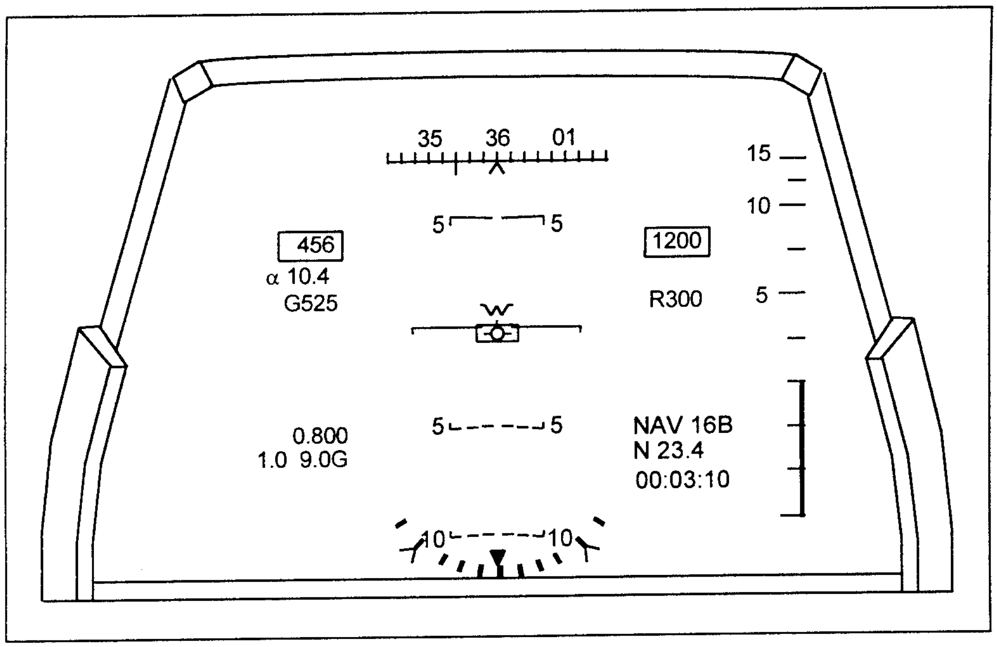

Figure 2.3.1 HUD Symbology

REMARKS/LESSONS LEARNED

The above symbology was chosen for both the baseline and the IMPACT cockpit simulations.

HUD AIR-TO-GROUND SYMBOLOGY

In the air-to-ground master mode, the manual TF box, radar altitude scale, and bank angle scale are removed from the HUD. The continuously-displayed impact point (CDIP) pipper is added as shown in Figure 2.3.2. The displayed impact line (DIL) indicates the path where the bomb will fall, and the pipper indicates the instantaneous impact point for the bomb.

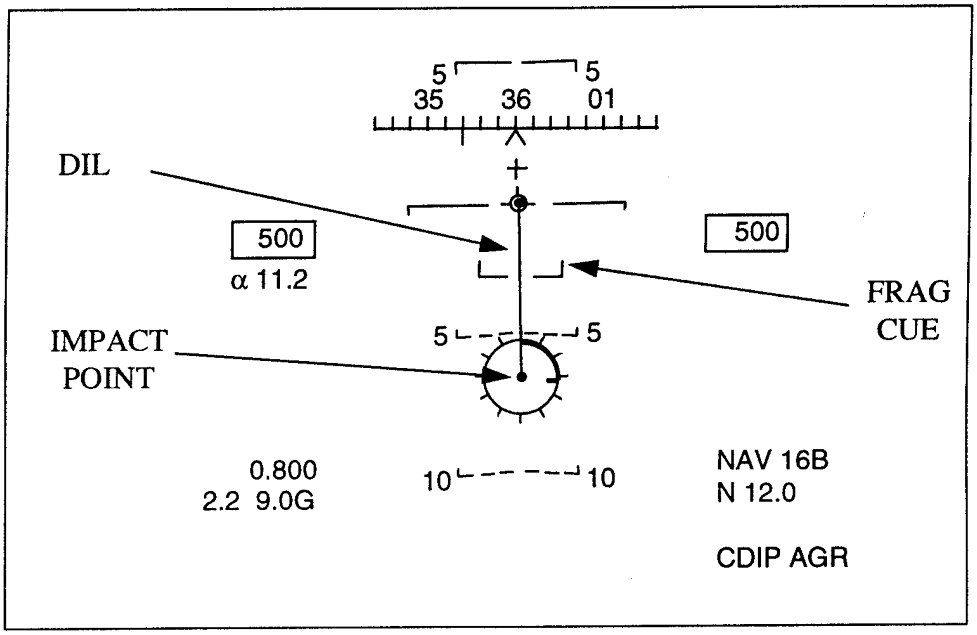

Figure 2.3.2 Air-to-Ground HUD Symbology

REMARKS/LESSONS LEARNED

The above symbology was chosen for both the baseline and the IMPACT cockpit simulations. The frag cue and the range bar shown in Figure 2.3.2 were not used in Advanced Technology Experiment # 2.

SPMR 2.4

UP-FRONT CONTROL (UFC)

INTRODUCTION

The display surface for the Up-Front Control (UFC) in the IMPACT cockpit will be identical in form and function to the baseline UFC. (See SPMR 1.4.) It is illustrated in Figure 2.4.1.

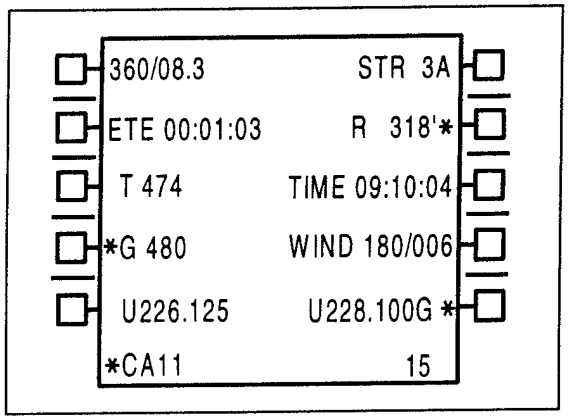

Figure 2.4.1 IMPACT UFC Data 1 Display

REMARKS/LESSONS LEARNED

The UFC for the IMPACT cockpit was an expedient design used to provide dynamic textual information comparable to that available in the baseline cockpit. No keypad design was incorporated, since it was known at the time the UFC was designed so that the pilot would not be required to interact with the display. Sufficient space exists to include a keypad in the vicinity of the display surface. The UFC is also a possible candidate for implementation of voice data entry.

SPMR 2.8

THREE-DIMENSIONAL (3-D) AUDIO

INTRODUCTION

The three-dimensional (3-D) audio capability for the IMPACT simulation shall be implemented via the Auditory Localization Cue Synthesizer (ALCS) system designed by Armstrong Laboratory. The ALCS encodes naturally occurring spatial information into an audio signal and presents a sound source that can vary in azimuth over stereo headphones incorporated into the pilot's helmet. The encoded signal sounds to the pilot as if it originated from a particular location. As the pilot changes head orientation, the relative position of the sound source is updated to make the sound appear stationary with the listening environment.

At least two different sounds will be used in the 3-D audio system: one for the surface-to-air threat and one for the air-to-air threat. The sounds will be activated simultaneously with the heads-down threat warning display of enemy radar lock-on and will stop on the test operator's input.

REMARKS/LESSONS LEARNED

Several changes were made in the implementation of the 3-D audio system as a result of pre-experimental study. The most significant change was the elimination of the elevation cue, resulting in a strictly azimuthal audio system. The change was made because of the necessity to operate the simulator intercom system through the same audio processing equipment as the directional audio system. Additionally, the sounds used in the system were changed significantly after consultation with representatives from Armstrong Laboratory. In an effort to provide better directional resolution, the clear tones initially chosen for threat annunciation were replaced with multi-spectral "pink" noise. The same intermittent sound was used for both surface and air threats, since the localization task was essentially identical for both types of threats. The sound continued as long as a threat was active. Armstrong Laboratory also provided new headphones to replace the relatively inexpensive ones supplied with the helmet. The new headphones provided significantly better sound quality and helmet fit.

SPMR 2.9

TERRAIN-FOLLOWING (TF) RADAR

INTRODUCTION

The IMPACT Terrain-Following (TF) radar display, shown in Figure 2.9.1, will be generated based on the DTED database. A manual TF command box will be displayed here and in the HUD to aid the pilot in maintaining terrain clearance.

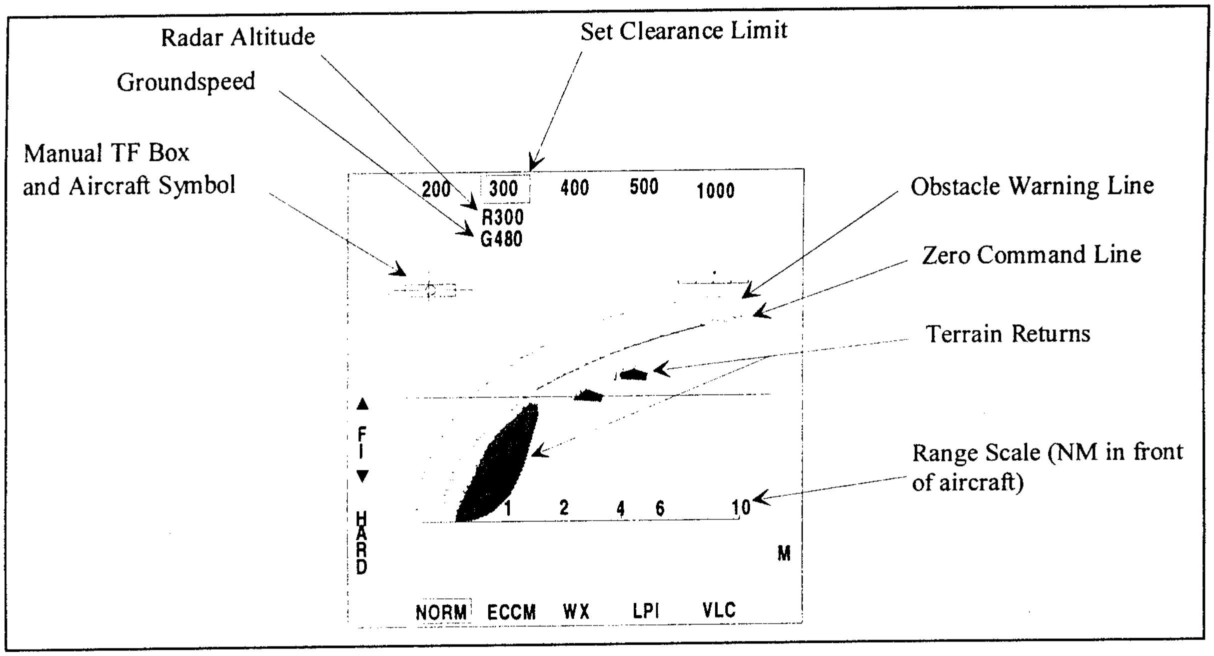

Figure 2.9.1 TF Radar Display

DISPLAY MENU SELECT

To select the Display Menu, the pilot will press (or use the TDC to click) the "M" pushbutton at the lower right corner of the display.

REMARKS/LESSONS LEARNED

The TF radar display was implemented as described above, with the following exceptions: The pilot was neither required nor able to change any of the display functions, including the set clearance limit. A constant 300 foot set clearance limit, with smooth ride, was selected for the scenario used in the simulation. The obstacle warning line was not implemented.

Note: The baseline and IMPACT TFR displays were essentially the same except that the baseline was a 6" square format and the IMPACT was a 5" square format.

SPMR 2.10

TACTICAL SITUATION DISPLAY (TSD)

INTRODUCTION

The tactical situation display (TSD), shown in Figure 2.10.1, consists of the mission route and steerpoint symbols displayed over a computer-generated moving map. The terrain features will come from the DTED database. Threat rings are positioned at the known threat locations. The display ranges are 10, 20, 40, 80, and 160 NM.

The steerpoint symbols are circles, and the target symbol is a triangle. Each steerpoint symbol is labeled, and the heading to the next steerpoint is displayed at the beginning of each segment. The aircraft symbol is centered in a compass rose and is located 1/4 of the display height from the bottom. The pilot shall have the ability to place the symbol in the center of the display, if desired. Friendly and enemy aircraft are displayed on the TSD based on ownship radar or data-linked information.

When the aircraft is retasked inflight, a message will appear on the TSD to alert the pilot. By selecting pushbuttons, the pilot can preview the new route, time, fuel, weather, threats, and support asset locations. Specifics for the mechanization of these functions will be included in updates to this SPMR.

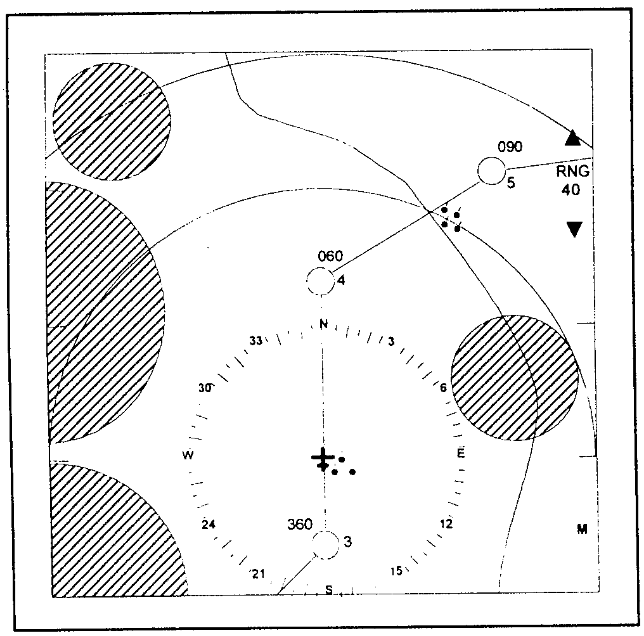

Figure 2.10.1 Tactical Situation Display

SURFACE-TO-AIR THREATS

Surface-to-air threats will be displayed on the TSD based on pre-mission planning, data-linked information, or ownship estimate of location after a threat radar locks onto the aircraft. These

threats will be displayed as hexagons, with the identifier in the center (Figure 2.10.2). After a threat locks onto the aircraft, a solid RED line will connect the threat symbol and the aircraft symbol (Figure 2.10.3). If there is ambiguity as to whom the threat has locked, two solid lines will "fan out" from the threat symbol (Figure 2.10.4).

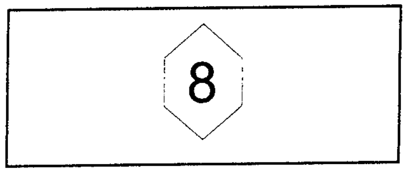

Figure 2.10.2 Surface-to-Air Threat Symbol

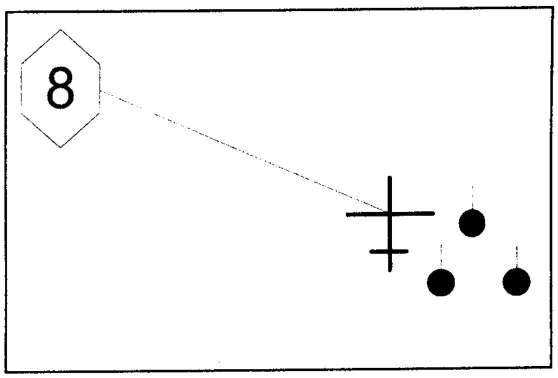

Figure 2.10.3 Threat Locked Onto Aircraft

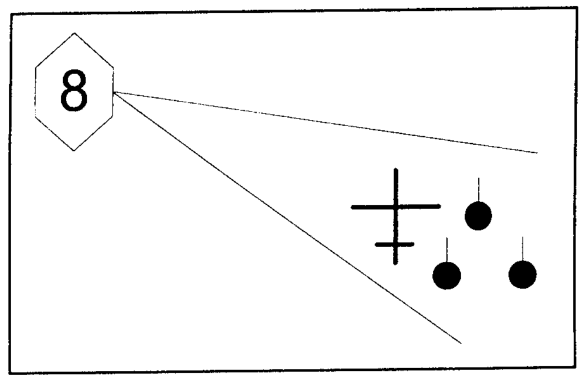

Figure 2.10.4 Threat Lock-On Ambiguity

The assumption is that advanced fighters will have on-board systems that can detect and track enemy surface-to-air missiles inflight. On the IMPACT TSD, a surface-to-air missile (SAM) will be displayed as a solid RED triangle with a velocity vector, connected to the threat symbol by an ORANGE line. The missile's relative elevation (in degrees) will be displayed above the threat symbol, and time to impact (in seconds) will be displayed below it (Figure 2.10.5).

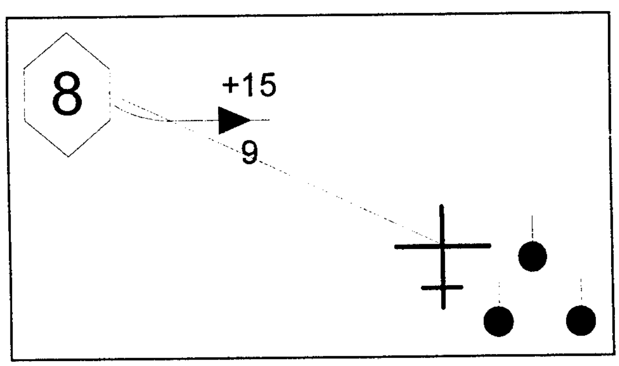

Figure 2.10.5 Missile Elevation (+15 deg) and Time to Impact (9 sec)

If the aircraft maneuvers after missile launch, the lethality of the threat decreases (even though the threat radar may still be locked onto the aircraft). This decrease in Pk is shown by dashed, then dotted lines from the threat symbol to the aircraft symbol (Figure 2.10.6). If aircraft

maneuvers, ECM or expendables break the lock of the radar or missile, the line is removed from the TSD. The missile will be displayed as long as the aircraft is able to track it.

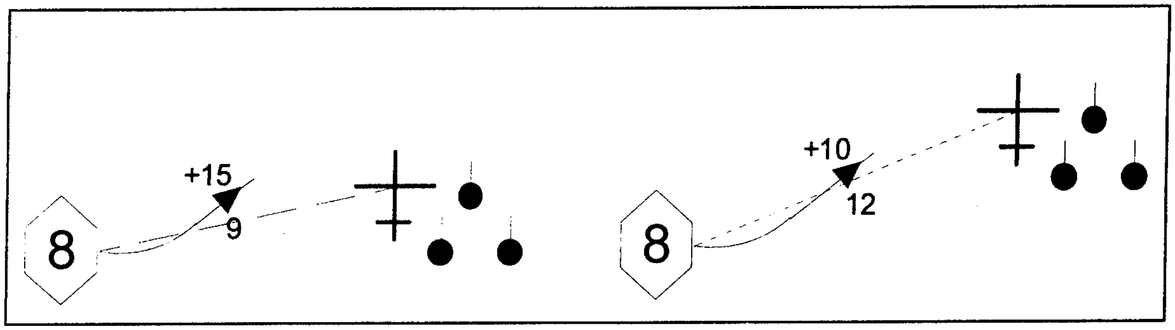

Figure 2.10.6 Decrease In Missile Lethality (Pk)

The TSD will automatically change to 10 NM range scale when a missile inflight reaches 10 NM from the aircraft (Figure 2.10.7). If another threat locks onto the aircraft, the pilot must expand the TSD scale to determine the threat type and location.

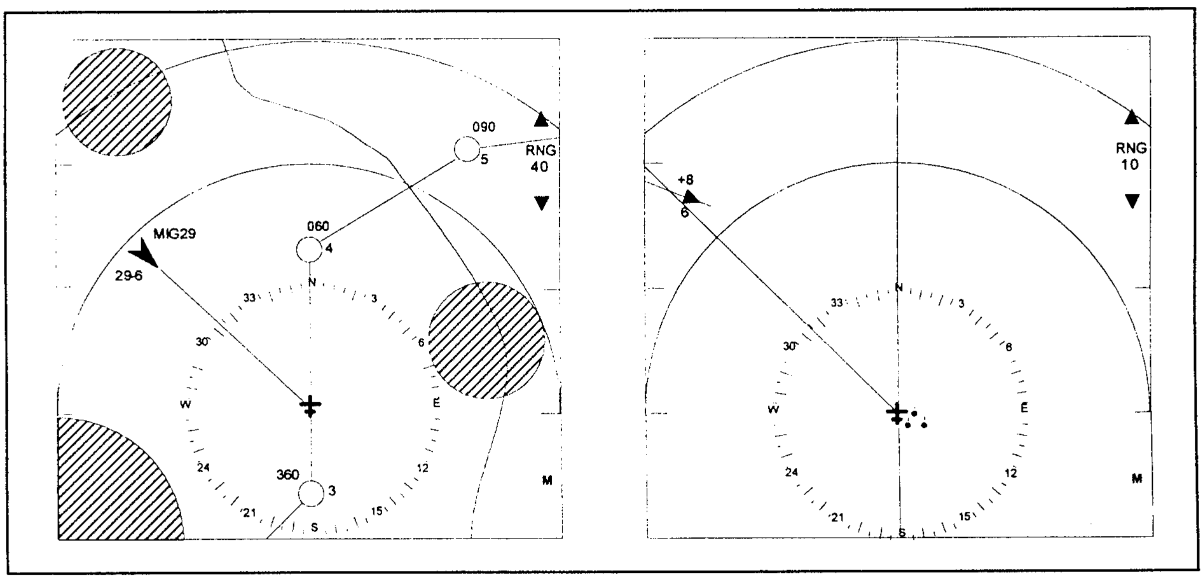

Figure 2.10.7 TSD When Nearest Missile Is Inside 10 NM

DISPLAY OF AIRCRAFT

Aircraft will be displayed on the TSD based on ownship radar information, data-linked information, or ownship estimate of location after an airborne radar locks onto the aircraft. Friendly aircraft have a unique symbol (GREEN circle with velocity vector). Unknown aircraft will be ORANGE, and enemy aircraft will be RED. Their airspeed will be shown using distinct symbols (Figure 2.10.8). The symbols will include an aircraft identifier (if known) and altitude. The heading of the airborne contact is denoted by the direction in which the symbol is pointing. Future updates to this SPMR will include symbology for air-to-air missiles inflight.

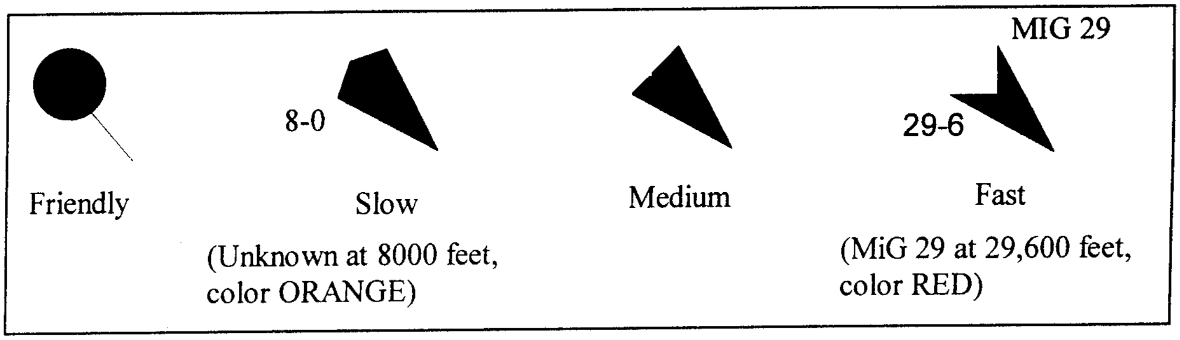

Figure 2.10.8 TSD Aircraft Symbols

REMARKS/LESSONS LEARNED

In Advanced Technology Experiment # 2, a simplified version of the TSD was implemented. In the scenario used during the experiment, the airborne and SAM threats were stationary in space, so the symbols used to represent them moved only as a result of aircraft motion. Missile launch symbology like that shown in Figure 2.10.5 was used to represent surface-to-air threats, and "fast" aircraft symbols (like the MiG-29 in Figure 2.10.8) represented the air-to-air threats. The TSD range was fixed at 40 NM.

SPMR 2.11

WEAPONS/COUNTERMEASURES (WPNS/CM) DISPLAY

INTRODUCTION

The Weapons/Countermeasures (WPNS/CM) display, shown in Figure 2.11.1, contains the following data: a graphical representation of all weapons loaded on the aircraft; a RDY (ready) indication when all pre-release functions have been met; chaff and flare counters with the bundles remaining highlighted; the release pulse selected (single, multi, or program); and the internal electronic countermeasures (ECM) status (off, standby, operate).

The WPNS/CM display will be a static picture for Advanced Technology Experiment # 2.

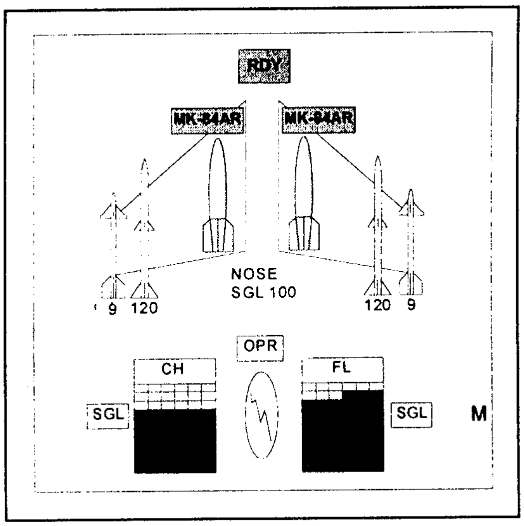

Figure 2.11.1 WPNS/CM Display

DISPLAY MENU SELECT

To select the Display Menu, press (or use the TDC to click) the "M" pushbutton at the lower right corner of the display.

REMARKS/LESSONS LEARNED

The WPNS/CM display used in Experiment # 2 appeared as shown in Figure 2.11.1. Two functions on the display were dynamic to provide feedback to the pilot: 1) The chaff display indicated expenditure of one bundle each time the paddle switch (chaff dispense) was depressed, and 2) The Mk-84 icons were removed when the pilot simulated release of the weapons.

SPMR 2.12

ATTITUDE DIRECTOR INDICATOR (ADI)

INTRODUCTION

The attitude director indicator (ADI) display contains the ADI, a heading scale, a terrain-following pitch steering bar, and a radar altitude scale, as shown in Figure 2.12.1. These objects are generated by the aero model and move in real-time as the pilot flies the aircraft. Calibrated airspeed is boxed and displayed on the left side of the ADI. The barometric altitude is boxed and displayed on the right side of the ADI, and the radar altitude is displayed below it, preceded by an "R."

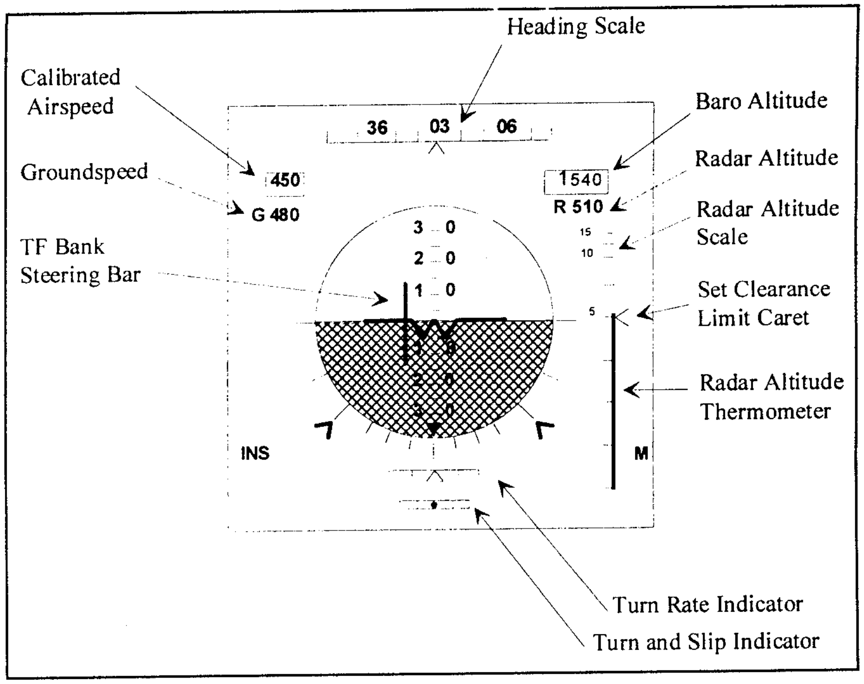

Figure 2.12.1 ADI

DISPLAY MENU SELECT

To select the Display Menu, press (or use the TDC to click) the "M" pushbutton at the lower right corner of the display.

REMARKS/LESSONS LEARNED

The ADI was implemented as described above for Advanced Technology Experiment # 2. The color version of this ADI (based on the F-15E color scheme) was placed in the upper right corner of the left 10 x 10 inch display surface on the simulator's large-screen CRT (simulated instrument panel). The color version of this ADI was easier to interpret in unusual attitudes than the version placed on the monochrome display as described in SPMR 1.12.

SPMR 2.14

ENGINE/FUEL DISPLAY

INTRODUCTION

The engine/fuel display, shown in Figure 2.14.1, contains graphic representations of the two engines and the fuel tanks. The following parameters are shown:

- Engine speed in per cent RPM, fuel flow (FF) in pounds per hour, temperature (TEMP) in degrees Celsius, nozzle position (NOZ) in per cent open, oil pressure (OIL) in pounds per square inch, and hydraulic pressure (HYD) in pounds per square inch for the aircraft's two hydraulic systems.

- Total fuel quantity in pounds, displayed above the fuel tank graphic, and a pictorial representation of the amount of fuel remaining in each tank (internal and external wing tanks, internal fuselage tanks).

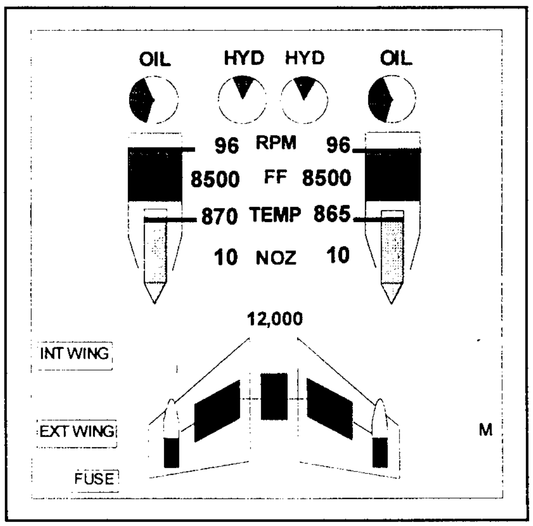

Figure 2.14.1 Engine/Fuel Display

FUEL QUANTITY SELECT

The pilot can determine the amount of fuel remaining in the internal and external tanks by selecting the INT WING, EXT WING, or FUSELAGE pushbuttons. When selected, those tanks will be highlighted, and the amount of fuel remaining will be displayed at the top of the fuel display. To return to the total fuel quantity display, deselect the pushbutton.

DISPLAY MENU SELECT

To select the Display Menu, press (or use the TDC to click) the "M" pushbutton at the lower right corner of the display.

REMARKS/LESSONS LEARNED

This display's appearance was implemented as described above for Advanced Technology Experiment # 2. The pilot was not required to interact with the display by changing display modes or selecting the Display Menu, so those capabilities were not implemented.

SPMR 2.15

HELMET-MOUNTED DISPLAY (HMD)

INTRODUCTION

The Kaiser SIM-EYE 40 helmet-mounted display (HMD) will be used to display navigation, threat warning, air-to-ground weapon delivery, and general situation awareness symbology. The HMD will also be used to display threat symbols for SAMs and air threats in both the IMPACT and baseline cockpits (see SPMR 3.5). This SPMR focuses on the symbology requirements for the HMD.

HMD SYMBOLOGY MAPPING ORIENTATION

Figure 2.15.1 illustrates the reference grid for mapping and placement of the HMD symbols and numeric information. The total dimensions are based on two 40° circular FOV displays, each with a resolution of 1280 x 1024 and a 50% overlap in the horizontal dimension. The grid's dimensions are milliradians (mr). It measures 1047 mr horizontally by 698 mr vertically. All symbology locations in this SPMR are referenced to the origin of the grid (coordinates 0,0).

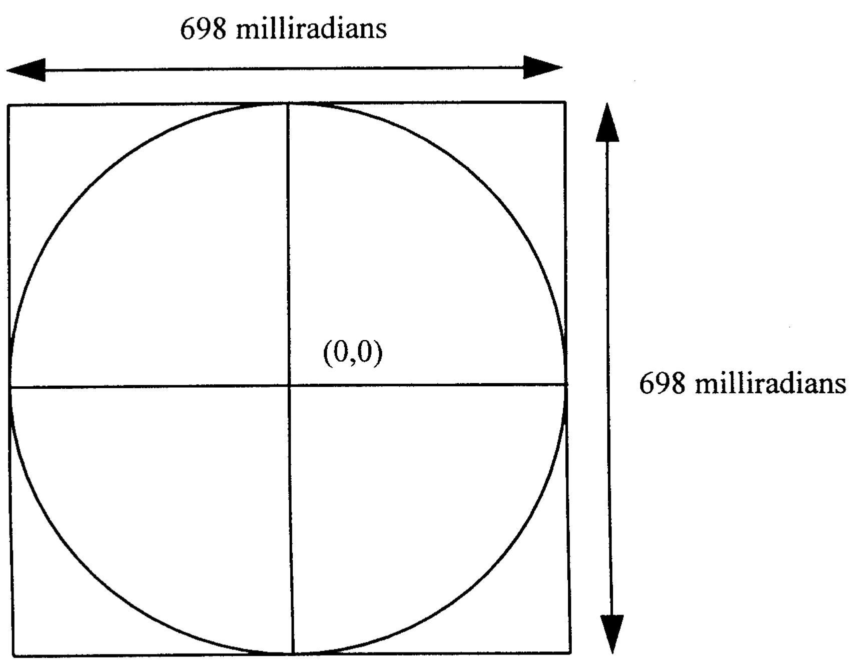

Figure 2.15.1 HMD Grid Reference

Figure 2.15.2 illustrates the NAV master mode symbology requirements. The NAV master mode display includes dedicated windows for digital information and dynamic symbology as the situation warrants. When the pilot is looking within ± 108 degrees of the HUD boresight the HMD symbology should be removed. The following paragraphs describe each requirement in detail.

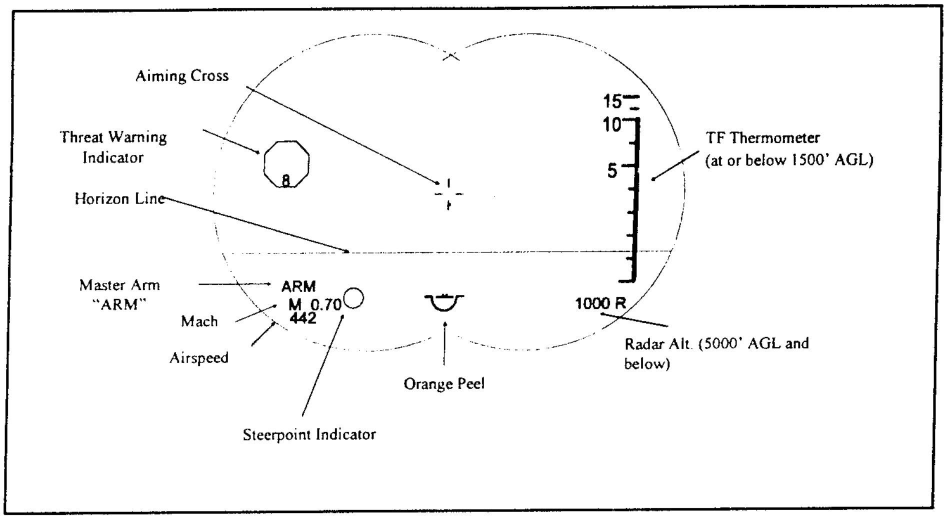

Figure 2.15.2 NAV Master Mode Symbology

DEDICATED WINDOWS

Master Arm Indication - The legend "ARM" shall appear in a dedicated window whenever the master arm switch is in the ARM position. The lower left corner of the dedicated window should be located at approximately -430,-212 mr from the center point. The character height for the legend "ARM" shall be 7 mr (24 minutes of arc).

Mach Indication - The mach indication shall appear at all times and is designated with an "M" followed by the current mach value (to the second decimal place). The lower left corner of the dedicated window should be located approximately -430,-221 mr from the center point. The character height for the mach information shall be 7 mr (24 minutes of arc).

Airspeed Indication - The airspeed indication shall be displayed at all times as a digital indication of current calibrated airspeed. The lower left corner of the dedicated window should be located at approximately -430,-230 mr from the center point. The character height for the airspeed information shall be 7 mr (24 minutes of arc).

Altitude Indication - The digital altitude indication shall be displayed at all times. The digital attitude indication shall indicate radar altitude any time the aircraft is below 5000' AGL and shall be denoted be the legend "R" immediately preceding the digital indication. The digital indication shall display baro altitude any time the aircraft is above 5000' AGL. The digital information shall appear in a dedicated window that has the lower left corner positioned at approximately 340,-230 mr from the center point. The character height for the altitude information shall be 7 mr (24 minutes of arc).

HMD SYMBOLOGY

Attitude Indication - The orange peel (Figure 2.15.3) shall be displayed at all times and is used to indicate the aircraft attitude. The symbol consists of a "winged" arc and an aircraft symbol centered at 0,-210.

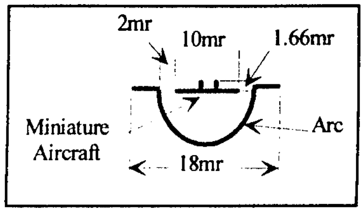

Figure 2.15.3 Orange Peel

Figure 2.15.4 illustrates the dynamics of the orange peel during a loop. At the start point, the wings of the arc are in line with the wings of the aircraft symbol. As the loop is initiated, the angle subtended by the arc decreases such that at the zenith the arc nearly disappears, leaving only the aircraft symbol wings visible. As the aircraft continues through the loop, the arc flips to the other side of the aircraft symbol. During the back portion of the loop the angle subtended by the arc increases. When at the horizon and when inverted, the arc is positioned above the aircraft symbol with its wings in line with the wings of the aircraft symbol. As the nose passes through the horizon, the angle subtended by the arc continues to increase until, when pointed straight down, the aircraft symbol is completely enclosed by the arc.

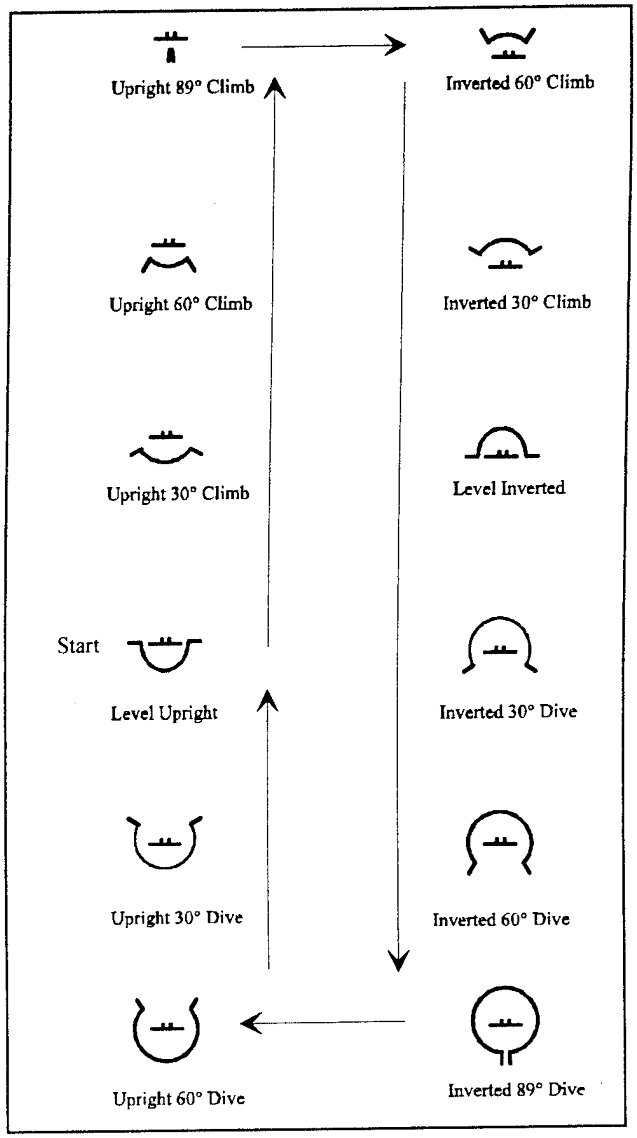

Figure 2.15.4 Orange Peel During A Loop

Roll is indicated by the opening of the arc rotating around the aircraft symbol, as indicated in Figure 2.15.5.

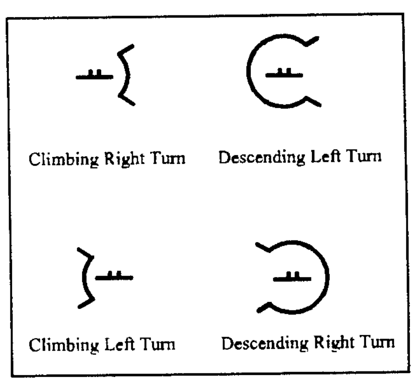

Figure 2.15.5 Orange Peel Indicating Roll

Altitude Thermometer - The radar altitude thermometer (Figure 2.15.6) shall be displayed whenever the radar altimeter is on and the aircraft is at 1500' or below. The character height for the digital information should be 4 mr (16 minutes of arc). The thermometer tape shall dynamically grow or shrink to reflect the current radar altitude. The thermometer shall be positioned directly above the digital altitude indication (Approximately 3 mr separation between the 0 tick mark and the digital indication).

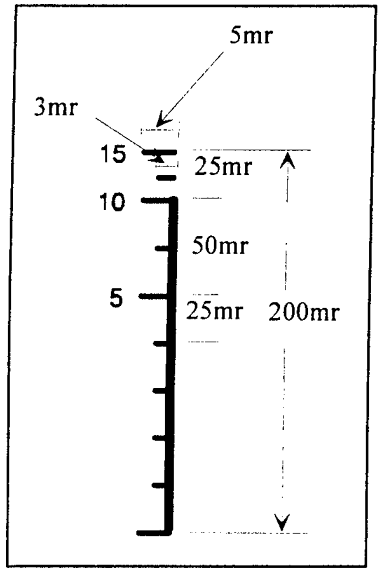

Figure 2.15.6 Radar Altitude Thermometer

Aiming Cross - The aiming cross (Figure 2.15.7) indicates the boresight of the HMD and shall always be displayed. The aiming cross shall be centered at 0,0 and will be used to designate points of interest.

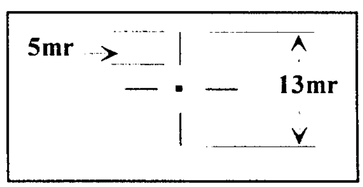

Figure 2.15.7 Aiming Cross

Horizon Line - The horizon line (Figure 2.15.9) shall be displayed at all times and shall be aligned with the true horizon. When the horizon is outside the HMD field-of-view (FOV) the horizon line shall become dashed and caged at the outer limits of the HMD.

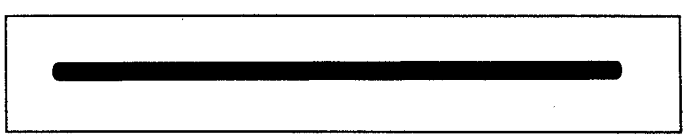

Figure 2.15.9 Horizon line

Steerpoint Indicator - The steerpoint indicator (Figure 2.15.10) is used for navigation to aid the pilot in visually acquiring waypoints. The symbol is dynamic and represents the position of the next steer-to-point. When the pilot's head is positioned so that the steerpoint is no longer within the HMD FOV, the steerpoint indicator shall be caged to the perimeter of the HMD.

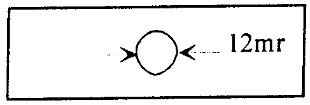

Figure 2.15.10 Steerpoint Indicator

Threat Warning Indicator - The threat warning indicator (Figure 2.15.11) shall be displayed whenever the radar warning receiver indicates that a threat has been detected. It shall be dynamic and represent the location of the threat.

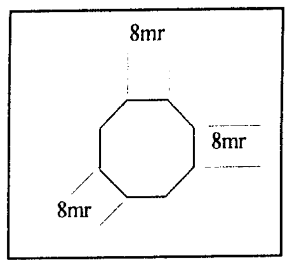

Figure 2.15.11 Threat Warning Indicator

Threat Locator Indicator - The threat locator indicator (Figure 2.15.12) shall be displayed whenever the threat is outside the HMD FOV. The tip of the lower chevron shall be displayed 10 mr inside the HMD perimeter and in the direction of the threat. When the threat is located behind the aircraft the chevron symbol shall become dashed.

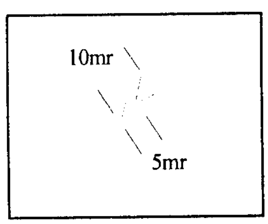

Figure 2.15.12 Threat Locator Indicator

A/G Weapon Delivery Symbology - When the air-to-ground (A/G) master mode is selected the radar altitude thermometer shall be removed and the following symbology shall be displayed as follows:

a. **Target Designator Diamond** - The target designator diamond (Figure 2.15.13) shall be displayed when the pilot selects A/G master mode and shall dynamically indicate the target location.

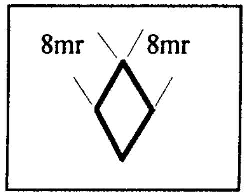

Figure 2.15.13 Target Designator Diamond

b. Target Locator Line - The target locator line (Figure 2.15.14) shall appear whenever the target is outside the HMD FOV. It shall originate from the center point (0,0) of the HMD and point in the direction of the designated target. The target designator diamond shall be removed when the target locator line is displayed.

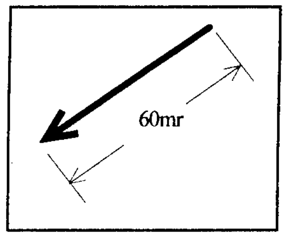

Figure 2.15.14 Target Locator Line

c. Target Range Indication - The target range indication shall appear when the A/G master mode is selected. The digital target range information shall appear directly under the target designator diamond or the tip of the target locator line. The character height for the target range information shall be 7 mr (24 minutes of arc).

REMARKS/LESSONS LEARNED

Several changes were made to the HMD symbology as a result of pre-experimental evaluation of the display. The resulting display had the arrangement shown in Figure 2.15.15. The following changes were implemented:

- A bi-ocular display was used instead of the planned 50% overlapped binocular display. This was necessary because of limitations on the number of computer video channels available. The same 40^{o} circular FOV display was presented to both of the pilot's eyes. Fixed symbology remained at approximately the same distance from each edge of the display as in the binocular version. The orange peel was located immediately below the center of the display.
- The orange peel was doubled in size. The original symbol was determined too small to be useful.
- The TF thermometer was moved 50 mr higher in the display to align it more naturally with the pilot's normal line of sight.
- The threat locator indicator (Figure 2.15.12) was replaced with a threat locator line that extended from the center of the HMD FOV in the direction of the threat. The threat locator line remained visible until the threat warning symbol was within the central 20^{o} (+\-10^{o} of

center) of the HMD FOV. This change was made because the threat locator indicator, at the perimeter of the HMD FOV, was difficult to see whenever the HMD's exit pupil was displaced by minor helmet slippage. The simultaneous presentation of the locator line and the threat warning symbol in the outer 10° FOV band eliminated the possibility that the line would disappear before the pilot could see the symbol.

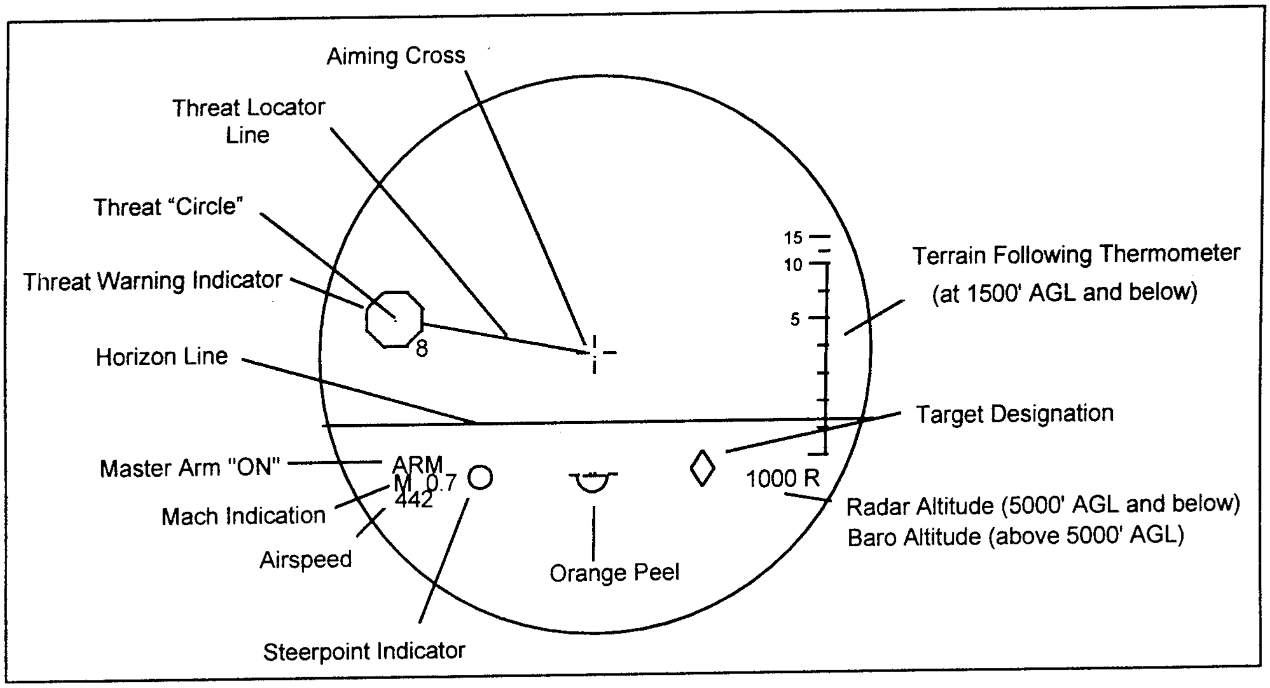

Figure 2.15.15 Modified HMD Symbology

SPMR 3.0

HUD DISPLAY ON BARCO PROJECTION SCREEN

INTRODUCTION

The HUD symbology described in SPMRs 1.3 and 2.3 will be presented on a Barco projection screen. The symbology for both cockpits is referenced to the screen by the horizon vision line (see Figure 3.0.1). This line extends horizontally from the design eye of the simulator to the (laterally measured) center of the projection screen. The HUD waterline symbol shall be located on the horizon vision line. The lower limits of the projection shall be 14.5° below the horizon vision line. The upper limits shall be 6.5° above the horizon vision line. The azimuth limits shall be ±14° from the horizon vision line.

The Barco projection screen speaker cover shall be centered and located 12 inches in front of the simulator's nose.

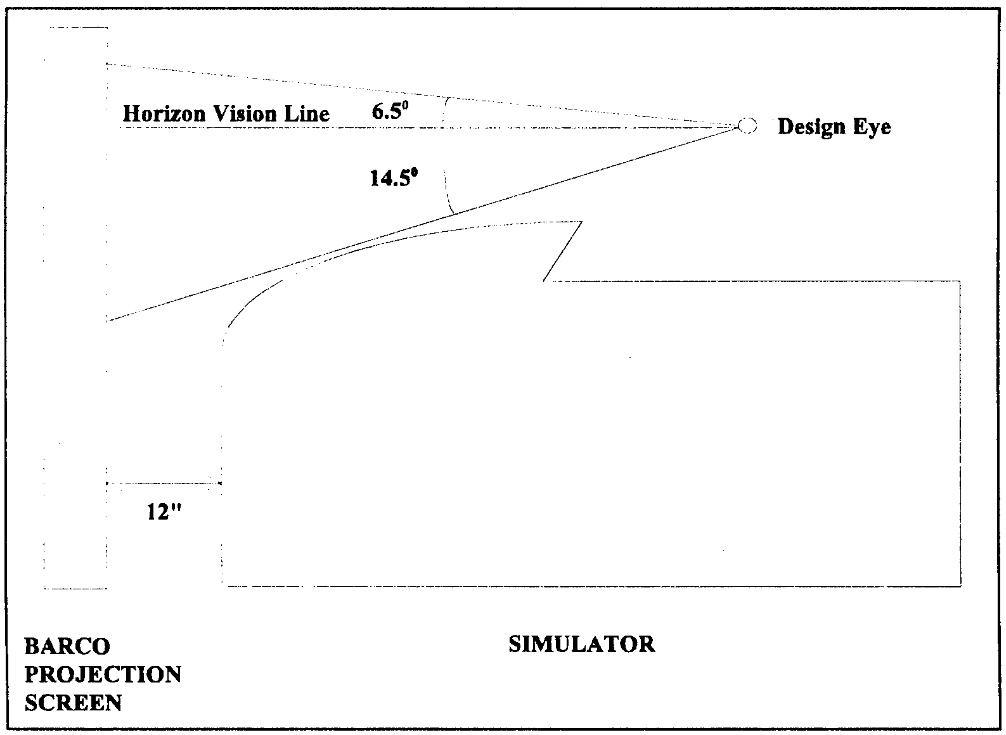

Figure 3.0.1 Location of Barco Projection Screen and Simulator

REMARKS/LESSONS LEARNED

The arrangement, shown in Figure 3.0.1, was satisfactorily used for Advanced Technology Experiment # 2.

SPMR 3.1

FORWARD-LOOKING INFRA-RED (FLIR) DISPLAY

INTRODUCTION

A simulated Low Altitude Navigation and Targeting Infra-Red for Night (LANTIRN) navigation pod forward-looking infra-red (FLIR) display will be depicted on the Barco projection screen, coincident with the 21 x 28 degree HUD presentation. The existing visual display capability of the simulation may be used. It should be presented in green monochrome. The visibility shall be adjustable by the software programmers. A simulated overcast shall restrict the view of the visual scene when the pilot is above or in it.

REMARKS/LESSONS LEARNED

The arrangement described was satisfactorily employed for Advanced Technology Experiment # 2. Some adjustments to the display and symbology brightness were required to accommodate the lack of background contrast when the simulated aircraft was flying through the clouds.

SPMR 3.2

OUT-THE-WINDOW DISPLAY

INTRODUCTION

Since the simulated mission is at night there will not be an out-the-window scene. The only terrain scene visible from either cockpit will be the HUD FLIR picture.

REMARKS/LESSONS LEARNED

The arrangement described was satisfactorily employed for Advanced Technology Experiment # 2.

SPMR 3.3

FEATURE ANALYSIS DISPLAY

INTRODUCTION

Visual scene features required for this experiment include roads, airfields, lakes, and dams within ± 10 NM of the course line. These items should be drawn to appropriate scale and match similar features on Defense Mapping Agency (DMA) Tactical Pilotage Chart (TPC) G-18A.

REMARKS/LESSONS LEARNED

The arrangement described was satisfactorily employed for Advanced Technology Experiment # 2.

SPMR 3.4

TARGETS

INTRODUCTION

The target will be displayed only when viewed through the simulated HUD FOV. It will have the appearance of a SCUD missile launcher. The target shall be capable of being positioned at multiple fixed geographical coordinates within the simulation database. The missile launcher will be visible when the aircraft arrives at the pull-up point for the weapon delivery. Illumination of the visual scene around the target shall be bright enough so that the target is easily discernible, but not so bright that it distracts the pilot.

REMARKS/LESSONS LEARNED

The arrangement described was satisfactorily employed for Advanced Technology Experiment # 2.

SPMR 3.5

THREATS

INTRODUCTION

The air-to-air and surface-to-air threat symbols shall only be displayed on the HMD (including when within ± 10 degrees of HUD boresight) in both cockpits. The symbols shall consist of solid circles, solid equilateral triangles, and solid squares. Each symbol shall be 14 mr on each side or in diameter (as appropriate) and green in color. Brightness shall be adjustable to achieve a level that permits the symbols to be barely distinguishable from the background (see Figure 3.5.1).

The threat symbols shall be positioned at fixed geographic positions and altitudes, the coordinates will be located in the threat database. The type of threat (circle, triangle, or square) to be displayed at designated points along the route will be identified with the experimental trials. The threat symbols will be extinguished when the pilot activates the chaff dispenser paddle switch on the base of the stick (see SPMR 1.1). If the pilot fails to activate the chaff dispenser switch, the threat will stay illuminated for 20 seconds.

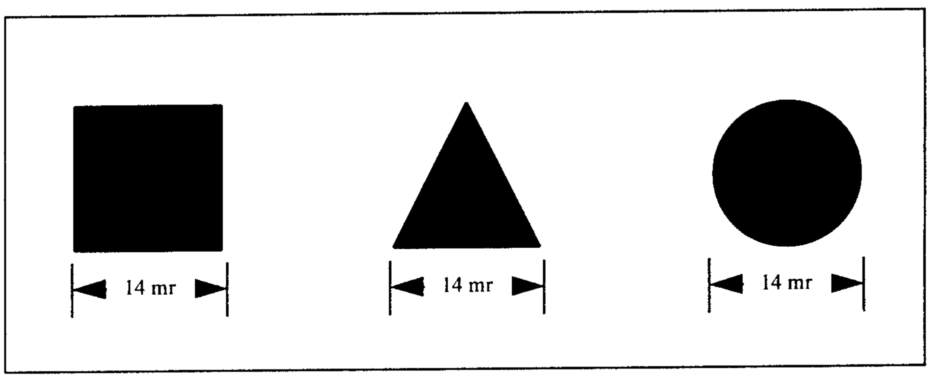

Figure 3.5.1 Threat Shapes

REMARKS/LESSONS LEARNED

Changes were made in the way the threats were presented to the pilots in Advanced Technology Demonstration # 2. The intent of using multiple shapes to represent the threats was to verify that the subject had a valid visual sighting (by requiring the subject to verbally identify the shape) when activating the chaff switch. However, since the experimenters were able to view a repeater of the HMD video, they could visually verify that the pilot was looking at the target, making verbal verification unnecessary. Additionally, it was discovered that for the geometric shapes to be large enough to identify, they had to be so large that they were noticed immediately whenever they fell within the HMD FOV. The experimenters felt that if the threats were this easy to see, the task difficulty would not be realistic. Consequently, the circle was selected as the threat symbol. The size and brightness of the threat symbol was reduced during pre-experimental sessions until the team agreed that an appropriate level of discernibility had been achieved.

APPENDIX B

PILOT FLYING EXPERIENCE

PILOT FLYING EXPERIENCE

Subject #	Aircraft #1	Hours	Aircraft #2	Hours	Aircraft #3	Hours	Aircraft #4	Hours	Total Hours
1	C-141	80	F-16	1350					1430
2	T-38	1800	F-4	1000	F-15	250			3050
3	F-16	700	OV-10	180	O-37	500	O-2	60	1440
4	F-16	750	F-4	820	F-106	690			2260
5	B-52	2500	T-37	400	T-38	250			3150
6	F-15	1350	T-37	1000					2350
7	F-16	220	A-7D	550					770
8	T-38	1200	F-111	900					2100
9	F-16C	430	F-4E	300	AT-38B	25	T-38A	120	875
10	A-7	320	F-4	700	T-38	120	T-37	80	1220
11	F-16	890	F-106	600	A-7	125	T-38	1300	2915
12	F-16	800	F-5	600	F-4	600			2000
13	F-15	900	F-4	950					1850
14	F-16	1200	OT-37	500	OV-10	300	O-2	300	2300
15	A-7D	1600	RF-4C	870	T39	1000			3470
16	TG-7A	150	B-52	2700	T-41	150			3000
17	F-111	1050	EF-111	1750					2800
18	F-111	800	F-15	2200	E-3	200			3200

Total Hours	Total Average Hours	Total Fighter Hours	Average Fighter/ Attack Hours
40180	2618	26745	858

APPENDIX C

QUESTIONNAIRES AND DATA COLLECTION FORMS

POST-MISSION INTERVIEW

Pilot Number _____ Trial Number _____ Date _________ Time __________

For trials 1, 2, 7, and 8 only:

Use the following numbers for recording pilot's responses to "rating scale questions:"

"1" for "Extremely Easy"
"2" for "Somewhat Easy"
"3" for "Neutral"
"4" for "Somewhat Difficult"
"5" for "Extremely Difficult"

1. Rate your **acquisition of threats** ____
2. Rate your **acquisition of the target** ____
3. Rate the effort required for **weapon delivery** ____
4. Rate the effort required for **flying the airplane precisely** ____

Continue with questions below.

For ALL trials:

5. Any comments on **threat acquisition**?

____

6. Any comments on **target acquisition**?

____

7 Any comments on **weapon delivery**?

____

7 Any comments on flying the **airplane precisely**?

____

7 Any **other comments**?

____

OUTBRIEF QUESTIONNAIRES

Name ______________________ Date ______________________

GENERAL INSTRUCTIONS: There are two questionnaires in this packet. In the first questionnaire, you will be asked to provide your opinion of various aspects of the two cockpits you have just flown. The second questionnaire asks you to evaluate the way the study was conducted. Please feel free to add comments on any of the questionnaire topics. If you don't understand a question, we'll be happy to explain it and/or discuss it with you. Thanks for your participation.

HMD AND TSD SYMBOLOGY

In this questionnaire, please tell us what you think about the value and acceptability of each individual element of symbology used in the HMD and TSD. Fill in each block below with a number (including "+" or "-" sign) or a letter as directed. For example, if you thought the Threat Cueing symbol "substantially enhanced" your ability to control the aircraft, enter a +2 in the "Threat Cueing Symbol" row in the "Control Aircraft" column. If you thought the Horizon Line was acceptable, but would like to suggest some changes, enter a "B" in the "Design & Mechanization" column AND write your suggestions/comments on the back of this page.

+2	Substantially Enhanced
+1	Moderately Enhanced
0	No Effect
- 1	Moderately Degraded
- 2	Substantially Degraded

A	Acceptable As Is
B	Acceptable, But I'd Like To See Changes
C	Totally Unacceptable

	Determine Threat Azimuth	Det. Threat Elevation	Determine Threat Range	Locate Target	Deliver Weapon	Maintain S/A (Incl. Nav)	Control Aircraft	Design & Mechanization
HMD								
Threat Cueing Symbol								
Target/Waypoint Cues								
Horizon Line								
Aiming Cross								
Master Arm Indication								
Mach Indication								
Airspeed Indication								
"Orange Peel" (Att. Ind.)								
Radar Altitude Scale								
Baro Altitude Indication								
TSD								
Aircraft Symbol								
SAM Threat Symbol								
Air-to-Air Threat Symbol								
Waypoint Symbol								
Course Line								

Use this space to provide comments about your responses on the front of this page.

COMMENTS ON HMD AND TSD SYMBOLOGY

HMD

Threat Cueing Symbol

Target/Waypoint Cues

Horizon Line

AOA Indicator

Master Arm Indication

Mach Indication

Airspeed Indication

"Orange Peel" (Attitude Indicator)

Radar Altitude Scale

Barometric Altitude Indication

TSD

Aircraft Symbol

SAM Threat Symbol

Air-to-Air Threat Symbol

Waypoint Symbol

Course Line

COCKPIT EFFECTIVENESS FOR SELECTED MISSION FUNCTIONS

Please tell us how effective the baseline and IMPACT cockpits were in enabling you to accomplish each of the mission functions listed below by placing the appropriate number (and sign) in each box. For example, if you thought the baseline was "Very Effective" in enabling you to determine threat azimuth, enter a +3 in the "BASELINE" row under the "Determine Threat Azimuth" column. Please enter a number in each box. Use the back of the page for comments.

+3 Very Effective
+2 Moderately Effective
+1 Slightly Effective
0 Ineffective

	Determine Threat Azimuth	Det. Threat Elevation	Determine Threat Range	Locate Target	Deliver Weapon	Maintain S/A (Incl. Nav)	Control Aircraft
BASELINE							
IMPACT							

IMPACT TECHNOLOGIES' CONTRIBUTIONS TO MISSION FUNCTIONS

Now, tell us what the contributions of the HMD, TSD, and directional audio were in enabling you to accomplish the same mission functions. Again, enter the appropriate number (and sign) in each box. (Note that the rating scale has changed.) For example, if you thought the HMD made a "Strong Negative Contribution" (e.g., really hampered) to your ability to control the aircraft, enter a "-3" alongside HMD, under the "Control Aircraft" column. Please enter a number in each box. Use the back of the page for comments.

+2 Strong Positive Contribution
+1 Moderate Positive Contribution
0 No Contribution
-1 Moderate Negative Contribution
-2 Strong Negative Contribution

	Determine Threat Azimuth	Det. Threat Elevation	Determine Threat Range	Locate Target	Deliver Weapon	Maintain S/A (Incl. Nav)	Control Aircraft
HMD							
TSD							
DIRECTIONAL AUDIO							

Use this space to provide comments about your responses on the front of this page.

COMMENTS ON COCKPIT EFFECTIVENESS FOR SELECTED MISSION FUNCTIONS

Please indicate the specific function you're commenting on (e.g., "Determine Threat Elevation").

BASELINE

IMPACT

COMMENTS ON IMPACT TECHNOLOGIES' CONTRIBUTIONS TO MISSION FUNCTIONS

Please indicate the specific function you're commenting on (e.g., "Determine Threat Elevation").

HMD

TSD

DIRECTIONAL AUDIO

ACCEPTABILITY OF HMD, TSD, AND DIRECTIONAL AUDIO DESIGN CHARACTERISTICS

Please rate the acceptability of the characteristics of the IMPACT technologies listed below. For each characteristic, enter a check mark in the box that corresponds to the appropriate rating category. (Check only one box per row). Use the back of this page for comments.

	Completely Acceptable	Moderately Acceptable	Borderline	Moderately Unacceptable	Completely Unacceptable
HMD					
Comfort					
Field-of-View					
Brightness and Contrast					
Focus					
Color					
Alignment with "World"					
Dynamics/Update Rate					
TSD					
Size					
Color Coding					
Brightness and Contrast					
Scaling					
Location					
DIRECTIONAL AUDIO					
Volume					
Frequency					
Method (Tone)					

Use this space to provide comments about your responses on the front of this page.

ACCEPTABILITY OF HMD, TSD, AND DIRECTIONAL AUDIO DESIGN CHARACTERISTICS

HMD

Comfort

Field-of-View

Brightness and Contrast

Focus

Color

Alignment with "World"

Dynamics/Update Rate

TSD

Size

Color Coding

Brightness and Contrast

Scaling

Location

DIRECTIONAL AUDIO

Volume

Frequency

Method (Tone)

OTHER COMMENTS

Here's your last chance to comment on any aspect of either cockpit design.

1. What is your overall impression of the capability of the baseline cockpit with regard to threat acquisition and night pop-up attacks?

2. What is your overall impression of the capability of the IMPACT cockpit with regard to threat acquisition and night pop-up attacks?

3. Are there any other technology applications that you think would be useful in helping fighter pilots locate threats and apply more aggressive bombing tactics at night?

METHODOLOGY AND PROCEDURES QUESTIONNAIRE

The following questionnaire, to be completed anonymously unless you care to attach your name for follow-up discussion, was developed so that you could provide feedback to the project team for improving future studies. Your comments are valuable to us and are greatly appreciated.

1. Overall, how would you rate the simulator formats used in this study?

BASELINE		IMPACT	
Exceptional	__	Exceptional	__
Good	__	Good	__
Fair	__	Fair	__
Poor	__	Poor	__
Unacceptable	__	Unacceptable	__

Do you have any other comments on this topic?

____

____

2. How would you rate the questionnaires and interviews used in this study?

Exceptional __
Good __
Fair __
Poor __
Unacceptable __

Do you have any other comments on this topic?

____

____

3. Overall, how would you rate the data collection procedures?

Exceptional __
Good __
Fair __
Poor __
Unacceptable __

Do you have any other comments on this topic?

____

____

4. How would you rate the quality of training (briefings, hands-on)?

Exceptional	__
Good	__
Fair	__
Poor	__
Unacceptable	__

Do you have any other comments on this topic?

____

____

5. How would you rate the "logistics" (e.g., scheduling) during your participation in this study?

Exceptional	__
Good	__
Fair	__
Poor	__
Unacceptable	__

Do you have any other comments on this topic?

____

____

6. How would you rate the staff that conducted this study in terms of knowledge, preparation, and professionalism?

Exceptional	__
Good	__
Fair	__
Poor	__
Unacceptable	__

Do you have any other comments on this topic?

____

____

7. What parts of the study do you think should be improved and why?

____

____

8. Do you have any other comments about this study?

____

____

Biographical Data

Name:____________________________________ **Date:**____________

Grade: O-1 O-2 O-3 O-4 O-5 O-6

Status: ____________ (Active Duty, Guard, Reserve, Retired)

Organization: ______________________________

Duty Station: ______________________________ **Duty Phone:** ______________________

Supervisor's name and address:____

(to be used for sending a letter of appreciation for participation in the study)

Aeronautical Rating: (please check one)

____ Pilot

____ Instructor Pilot

____ Evaluator Pilot

May we contact you if additional information is needed? ____________

Please list aircraft flown and approximate number of hours in each, beginning with the most recent:

Aircraft:	**Hours:**
____________	____________
____________	____________
____________	____________
____________	____________

Other qualifications (FWIC graduate, Test Pilot School graduate, RTU Instructor): ____________

____

Desert Storm experience? ____ Yes ____ No

Specific operational experience: please check experience level for each category:

	limited	moderate	extensive
Low-level fighter, manual TFR	______	______	______
RWR and defensive threat reactions	______	______	______
Air-to-ground weapon delivery	______	______	______

Advanced Technologies: please list your knowledge of the following technologies:

	no knowledge	little knowledge	much knowledge
Directional Audio	______	______	______
Helmet-Mounted Displays/Sights	______	______	______
Large format TSDs	______	______	______

Real-Time Data Probes

Pilot Number _____ Trial Number _____ Date __________ Time __________

Medium altitude segment

Identification of Threat 1 (circle one) **sighting** **no sighting**

After dispensing chaff for Threat 1 **SWAT** _____ _____ _____

Turning descent

Identification of Threat 1 (circle one) **sighting** **no sighting**

After dispensing chaff for Threat 2 **SWAT** _____ _____ _____

Low-level ingress and turn to IP

Identification of Threat 1 (circle one) **sighting** **no sighting**

After dispensing chaff for Threat 3 **SWAT** _____ _____ _____

Identification of Threat 1 (circle one) **sighting** **no sighting**

After dispensing chaff for Threat 4 **SWAT** _____ _____ _____

Weapon delivery

After attacking target **SWAT** _____ _____ _____

Comments: ____

____

____

____

____

SUBJECT # ______

Which Cockpit Configuration / Function Supports Better Situation Awareness?

	>>>>		>>>		>>		>		EQUAL		<		<<		<<<		<<<<	
Baseline - TH AQ	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	Baseline - TG AQ
Baseline - TH AQ	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	Baseline - FLY / N
Baseline - TH AQ	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	IMPACT - TH AQ
Baseline - TH AQ	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	IMPACT - TG AQ
Baseline - TH AQ	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	IMPACT - FLY / N
Baseline - TG AQ	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	Baseline - FLY / N
Baseline - TG AQ	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	IMPACT - TH AQ
Baseline - TG AQ	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	IMPACT - TG AQ
Baseline - TG AQ	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	IMPACT - FLY / N
Baseline - FLY / N	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	IMPACT - TH AQ
Baseline - FLY / N	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	IMPACT - TG AQ
Baseline - FLY / N	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	IMPACT - FLY / N
IMPACT - TH AQ	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	IMPACT - TG AQ
IMPACT - TH AQ	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	IMPACT - FLY / N
IMPACT - TG AQ	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	___	IMPACT - FLY / N

COCKPIT CONFIGURATION:
Baseline
IMPACT

FUNCTION:
TH AQ = THREAT ACQUISITION
TG AQ = TARGET ACQUISITION
FLY / N = FLYING NAVIGATION

APPENDIX D

EXPERIMENTAL DESIGN

EXPERIMENTAL DESIGN

SUBJECTS	TREATMENT FACTORS	TRIAL 1	2	3	4	5	6	7	8
1, 9	Cockpit	[illegible]	IMPACT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Target	Easy	Easy	Hard	Hard	Easy	Easy	Hard	Hard
	AA Threats	Easy, Hard	Hard, Easy	Hard, Easy	Hard, Easy	Hard, Easy	Easy, Hard	Easy, Hard	Hard, Easy
	SA Threats	Hard, Easy	Easy, Hard	Easy, Hard	Easy, Hard	Easy, Hard	Hard, Easy	Hard, Easy	Easy, Hard
2, 13	Cockpit	Baseline	IMPACT	Baseline	IMPACT	[illegible]	[illegible]	[illegible]	[illegible]
	Target	Easy	Hard	Hard	Easy	Hard	Easy	Easy	Hard
	AA Threats	Hard, Easy	Hard, Easy	Hard, Easy	Easy, Hard	Easy, Hard	Hard, Easy	Hard, Easy	Easy, Hard
	SA Threats	Easy, Hard	Easy, Hard	Easy, Hard	Hard, Easy	Hard, Easy	Easy, Hard	Easy, Hard	Hard, Easy
3, 10	Cockpit	Baseline	IMPACT	Baseline	IMPACT	IMPACT	Baseline	IMPACT	Baseline
	Target	Hard	Easy	Easy	Hard	Easy	Hard	Hard	Easy
	AA Threats	Hard, Easy	Easy, Hard	Hard, Easy	Easy, Hard	Easy, Hard	Easy, Hard	Hard, Easy	Easy, Hard
	SA Threats	Easy, Hard	Hard, Easy	Easy, Hard	Hard, Easy	Hard, Easy	Hard, Easy	Easy, Hard	Hard, Easy
4, 14	Cockpit	Baseline	IMPACT	Baseline	IMPACT	IMPACT	Baseline	IMPACT	Baseline
	Target	Hard	Hard	Easy	Easy	Hard	Hard	Easy	Easy
	AA Threats	Easy, Hard	Hard, Easy	Easy, Hard	Easy, Hard	Hard, Easy	Easy, Hard	Easy, Hard	Hard, Easy
	SA Threats	Hard, Easy	Easy, Hard	Hard, Easy	Hard, Easy	Easy, Hard	Hard, Easy	Hard, Easy	Easy, Hard
5, 11	Cockpit	IMPACT	Baseline	IMPACT	Baseline	Baseline	IMPACT	Baseline	IMPACT
	Target	Easy	Easy	Hard	Hard	Easy	Easy	Hard	Hard
	AA Threats	Easy, Hard	Hard, Easy	Hard, Easy	Easy, Hard	Easy, Hard	Easy, Hard	Hard, Easy	Hard, Easy
	SA Threats	Hard, Easy	Easy, Hard	Easy, Hard	Hard, Easy	Hard, Easy	Hard, Easy	Easy, Hard	Easy, Hard
6, 15	Cockpit	IMPACT	Baseline	IMPACT	Baseline	Baseline	IMPACT	Baseline	IMPACT
	Target	Easy	Hard	Hard	Easy	Hard	Hard	Easy	Easy
	AA Threats	Hard, Easy	Hard, Easy	Hard, Easy	Easy, Hard	Hard, Easy	Easy, Hard	Easy, Hard	Easy, Hard
	SA Threats	Easy, Hard	Easy, Hard	Easy, Hard	Hard, Easy	Easy, Hard	Hard, Easy	Hard, Easy	Hard, Easy
7, 12	Cockpit	IMPACT	Baseline	IMPACT	Baseline	Baseline	IMPACT	Baseline	IMPACT
	Target	Hard	Easy	Easy	Hard	Easy	Hard	Hard	Easy
	AA Threats	Easy, Hard	Easy, Hard	Easy, Hard	Hard, Easy	Easy, Hard	Hard, Easy	Hard, Easy	Hard, Easy
	SA Threats	Hard, Easy	Hard, Easy	Hard, Easy	Easy, Hard	Hard, Easy	Easy, Hard	Easy, Hard	Easy, Hard
8, 16	Cockpit	IMPACT	Baseline	IMPACT	Baseline	Baseline	IMPACT	Baseline	IMPACT
	Target	Hard	Hard	Easy	Easy	Hard	Easy	Easy	Hard
	AA Threats	Hard, Easy	Hard, Easy	Hard, Easy	Easy, Hard	Hard, Easy	Easy, Hard	Easy, Hard	Easy, Hard
	SA Threats	Easy, Hard	Easy, Hard	Easy, Hard	Hard, Easy	Easy, Hard	Hard, Easy	Hard, Easy	Hard, Easy

TARGET AND THREAT LOCATIONS

TARGET LOCATIONS			
Target	Longitude	Latitude	Altitude
T1	-120.805	37.177	1200
T2	-120.800	37.173	1200
T3	-120.810	37.178	1200
T4	-120.797	37.172	1200
T5	-120.813	37.180	1200
T6	-120.805	37.177	1200
T7	-120.768	37.140	1200
T8	-120.855	37.180	1200
T9	-120.792	37.168	1200
T10	-120.818	37.180	1200
T11	-120.780	37.158	1200
T12	-120.835	37.183	1200

SURFACE-TO-AIR THREAT LOCATIONS			
Threat	Longitude	Latitude	Altitude
B-1	-121.150	36.950	1500
B-10	-121.137	36.070	1500
B-2	-121.033	35.950	2000
B-3	-120.900	36.550	3700
B-4	-121.017	36.167	300
B-5	-120.900	36.833	2000
B-6	-120.767	36.000	2000
B-7	-121.133	36.383	1000
B-8	-121.000	36.200	1000
B-9	-121.078	36.148	500
F-1	-120.750	36.150	1500
F-10	-121.130	36.652	1500
F-11	-121.025	36.592	4000
F-12	-121.183	36.565	1500
F-2	-121.150	36.600	2000
F-3	-120.967	36.233	1000
F-5	-120.917	36.017	300
F-6	-120.983	36.883	1000
F-7	-120.867	36.100	300
F-8	-120.967	36.483	1000
F-9	-121.067	36.628	3600

AIR-TO-AIR THREAT LOCATIONS			
Threat	Longitude	Latitude	Altitude
E-1	-120.992	36.150	27500
E-2	-121.165	36.845	7800
E-3	-120.913	36.203	17700
E-4	-120.763	36.142	20500
E-5	-120.983	36.100	2000
E-6	-121.198	36.808	12500
E-7	-120.783	36.187	23300
E-8	-120.767	36.153	13500
E-9	-120.935	36.073	10000
E-10	-121.055	36.825	15200
E-11	-120.800	36.198	5000
E-12	-120.940	36.192	15500
E-13	-121.152	36.498	17500
E-14	-121.150	36.483	5500
E-15	-121.047	36.582	17500
E-16	-120.955	36.533	19500
E-17	-121.138	36.537	17500
E-18	-121.150	36.477	10500
H-1	-121.137	36.450	26600
H-10	-120.948	36.517	30000
H-11	-121.217	36.720	25000
H-12	-121.050	35.983	40000
H-13	-120.758	36.125	30000
H-14	-120.922	36.062	24900
H-15	-120.763	36.125	30000
H-16	-120.755	36.138	28500
H-17	-120.832	36.053	3000
H-18	-120.775	36.097	23500
H-2	-121.058	36.413	30200
H-3	-121.203	36.700	28900
H-4	-121.137	36.070	40000
H-5	-121.120	36.460	29600
H-6	-120.967	36.453	29600
H-7	-121.070	36.670	23300
H-8	-121.135	36.052	10000
H-9	-120.953	36.528	29000

APPENDIX E

PILOT COMMENTS

Pilots' Verbal Comments Regarding the IMPACT Configuration

Pilot	Rating	Comments
1	0	Since we used the same heads-down TSD and HUD in both cockpits, I gave the same rating to "Locate Target"and "Deliver Weapon."
	+	The TSD, Directional Audio and HMD combination made threat acquisition much easier. Also, the target locator cue made target acquisition easier.
	+	Directional audio helps.
	+	HMD arrow helps.
	0	Master moding should be on the UFC.
2	+	A vast improvement. Further effort is needed so FLIR image does not overwhelm the HMD. I felt there was too much difference in brightness (FLIR was too bright).
	+	I never would have found the 3rd threat w/o HMD cueing.
	+	Using the audio inputs takes some training. The HMD allows you to reduce turning the aircraft as much and to stay lower while finding the threats.
	+	Extremely easy in IMPACT.
	+	Acquiring threats was more difficult w/o cueing and less time for flying.
	+	Acquiring threats was extremely easy - Audio is not a strong signal - Left or right only and still glance at TSD to see threat.
	+	HMD really helps stay on course because it is easier to see the threats.
	-	It was difficult to use the helmet and HUD.
	+	Easier when using the HMD symbols (after 6th trial).

Pilots' Verbal Comments Regarding the IMPACT Configuration (cont.)

Pilot	Rating	Comments
3	+	Threat acquisition was outstanding! Like the "F-15E" [Baseline] this was no great leap from the Block 40 F-16.
	0	Not fully utilizing the HMD yet.
	+	Looked for target in the HMD and it worked!
	0	Tried to use the HMD, but went back to the HUD.
	+	TSD is good.
4	+	This is an improvement - a large improvement. Most of the improvement is due to the HMD.
	+	I like the cueing, can see the threats without moving the aircraft.
	0	The target is hidden by the target designator symbology sometimes.
	+	Used the HMD and it helped.
	-	Tried to use the HMD arrow to find the target, but became confused.
5	+	Very effective.
	+	Excellent! Very effective for threat recognition. Less effective for SA when transitioning to the HUD from the HMD.
	0	HMD is great for threats. Needs more work in target area.
	+	HMD is easy.
	+	Learning to turn head, using HMD symbology.
	-	The HMD diamond should be a different color.
	-	HMD to HUD requires reacquisition.
	+	In the IMPACT cockpit you look outside for the target. In the "F-15E" [Baseline], you have to look in to get SA.
	0	Engine instrument should be on the same side of both cockpits.
	-	IMPACT information sometimes overloads. Dimmer would help.
	-	HMD airspeed is not crisp.

Pilots' Verbal Comments Regarding the IMPACT Configuration (cont.)

Pilot	Rating	Comments
6	0	IMPACT makes weapon delivery easier, but I still feel that night low-level and night pop-up deliveries are a two person kind of job.
	+	Without helmet cueing, if you have to look past the beam, light pollution makes it hard to see threats. Breaking at 300 feet on instruments is tough.
	+	Pretty much a no-brainer. Pretty simple really with Threat Box - line aids in acquisition.
	-	On one of the threats close to six o'clock, when you move your head quickly, you may confuse threat location line with horizon line.
	0	For the first time today, I actually saw TD in helmet before it was uncaged in the HUD; I will start using it.
	+	Used helmet to see where to roll-out. Had more time than would have had otherwise.
	+	Difficult with big offset in the "F-15E" [Baseline] ... never know how far off. The HMD would have helped.
	+	Used helmet target designator until I got target underneath nose - made it easier.
	-	I picked it up in the HMD, pulled to it, then lost it in transition from HMD to HUD.
7	0	Range on audio would be nice.
	-	HMD symbology (alphanumerics) is blurry.
8	+	TA-Excellent, pop-up better than "F-15E" [Baseline].
9	+	The HMD helped a lot in determining azimuth and elevation of the threat, which was much superior to the basic "F-15E" [Baseline].
	+	The HMD in the IMPACT cockpit provided superior threat information (e.g., SA, Azimuth, and elevation), which was superior to the "F-15E" [Baseline] threat information. During NAV and weapon delivery, they were equal.
	-	During threat number one, I hit the ground and was totally disoriented.
	+	Like IMPACT better.
	+	Like threat line coming at you instead of somebody else.
	+	HMD is magical in finding threats.
	-	Don't like chasing digital airspeed indicator.
	-	Don't like engine instruments on the left.

Pilots' Verbal Comments Regarding the IMPACT Configuration (cont.)

Pilot	Rating	Comments
9	+	I like the TSD.
	+	The HMD helps immensely in finding threats in the IMPACT cockpit.
10	+	Much improved over the other and it allows one to control the aircraft better.
	-	Threat #2 had to adjust helmet (because of slippage) and never found threat.
	+	Like threat nomenclature on HMD.
11	+	2-D audio, HMD, very synergistic for threat azimuth. HMD with bore cross, target locator line was invaluable for off-boresight target acquisition.
	+	Much better, felt almost as comfortable at night as during day. Threat detect was much more of a non-event.
	-	Target locator line confused w/horizon - a dashed or double-line might help. I initially turned based on aural cue - peripherally aware of sound.
	0	Initial turn could have been due to audio - didn't look at TSD.
	+	Symbology was critical with finding threats quickly. Liked synergism of directional audio and HMD.
	+	You got to look inside with the "F-15E" [Baseline] for threats. With HMD you don't care.
	+	Directional audio just paid for itself. With a combination of HMD and audio, you could afford to be a little less precise.
	0	Target locator line in HUD would help.
	+	This was the first time I noticed the target in the HMD. Target locator line is there. Pulled down to it.
	+	Geometry of pop (in "F-15E" [Baseline]) was worse than I expected. Missed target locator line, which was what enabled me to find the target quicker in the IMPACT cockpit.
	+	The more off-boresight the target is, the more the advantages show.
	+	Really miss target locator line (in "F-15E" [Baseline]).
	0	Would rather have precision in HMD, if given the choice. There needs to be a magnitude of the off straight ahead look. Maybe make target water line proportional.
	+	The HMD makes finding threats easier - you don't realize how much until you switch back to the "F-15E" [Baseline].

Pilots' Verbal Comments Regarding the IMPACT Configuration (cont.)

Pilot	Rating	Comments
12	+	More suitable. Still need audio warnings. Much better at maintaining SA and capability at night in the weather.
	-	The threat radar and the missile flyout lines are confusing. They should be distinctly different.
	+	Threat line on HMD is great.
	-	The sudden appearance of the horizon line and the threat line together are confusing - I came back to the TSD. The threat line should be dotted.
	0	HMD pointer needs to point azimuth first, then elevation second as the pilot flies.
	+	Never acquired the target. I like the target arrow in HMD to help find target.
	+	The HMD target line is very helpful.
	+	Let's just use the IMPACT cockpit for the rest of the time.
	0	Directional audio test would be better if there was more background.
13	+	The TSD is very good, no notable +/- with "F-15E" [Baseline]. The Weapon/Threat designator on HMD is excellent!
	+	The threat acquisition is fantastic.
	+	I like the HMD threat arrow to locate threats.
	-	Threat cue for #2 was disorienting because of confusion with horizon line.
	-	There was confusion between the threat line and the horizon line.
14	+	Great benefit over "F-15E" [Baseline] for determining threat azimuth and elevation.
	+	Good improvement over "F-15E" [Baseline].
	-	Do not like the engine instruments in IMPACT - location or format.

Pilots' Verbal Comments Regarding the IMPACT Configuration (cont.)

Pilot	Rating	Comments
15	+	Impact is four times better at threat acquisition. Impact is about the same for pop-up attacks. Directional audio is a great enhancer. In the Impact cockpit, it is four times easier to detect threats and to fly at low altitude. Declutter the HUD during target acquisition.
	+	Helmet really decreases workload for threats.
	+	HMD arrow really helps find the threats.
	+	Audio is a big help for initial head movements.
	-	Too much HUD symbology.
	0	HUD declutter mode to erase some HUD symbology would be nice.
	+	IMPACT TSD is a lot better than "F-15E" [Baseline] TSD because it is larger and easier to read.
16	+	Arrows in HMD made threat acquisition significantly easier.
	+	HMD symbology helps.
17	-	Threat #1: Helmet slipped when turning. Threat #3: Helmet slipped again - Hit ground trying to put threat symbol on gun cross.
	+	Would not have found Threats #1 and #2 without HMD.
	+	For Threat # 1, I didn't even use TSD as an aid.
	+	It is difficult to find threats without HMD symbology.
	0	I look at the TSD first, but I'm becoming more familiar with using the HMD to find threats.
	+	Learning curve is going up. Like HMD symbology.
	+	Never would have found some of the threats without HMD symbology.
	+	HMD guides a lot quicker.
18	-	Threat acquisition is much improved. HMD weapon delivery - I wished many times that I could have turned the HMD off. For simple deliveries, it confuses more than it helps. The transition between HMD and HUD is poor.
	+	HMD target designator helped me find the target.
	-	I rolled right when target was left, then I lost the target in HMD and HUD symbology.

Pilots' Verbal Comments Regarding the "F-15E" [Baseline] Configuration

Pilot	Rating	Comments
1	0	Since we used the same heads-down TSD and HUD in both cockpits, I gave the same rating to "Locate Target" and "Deliver Weapon."
	0	It is adequate, but work is required to determine threat azimuth and range. As far as night pop-up attacks go, I think operational pilots fly directly to the target and do a direct pop (leaving offsets for daytime).
	0	Master-moding should be on the UFC.
	0	Have to look at the TEWS to find the threat.
	+	TD diamond is useful.
2	-	Poor at best.
	-	I do not want to return to the "F-15E" [Baseline] cockpit!
	0	Avoiding terrain was most difficult when acquiring threats.
	-	Disoriented after 2nd threat, used ADI to recover but was confused about the sky - ground contrast.
3	0	The TEWS was quite useful for both threat acquisition and situation awareness (great for SA). Rest of cockpit was no great leap from the Block 40 F-16.
4	-	Threat Elevation: In this simulation (i.e., no over-the-shoulder horizon), not knowing where to look in elevation makes it nearly impossible to find threat if the aircraft is being maneuvered. Not that bad in the real world.
	0	Your simulation does not do justice to the "F-15E" [Baseline] cockpit. Although IMPACT technologies would help, the real aircraft is not as bad as this test made it seem.
	+	"F-15E" [Baseline] engine instruments are easier to read than those in the IMPACT cockpit.

Pilots' Verbal Comments Regarding the "F-15E" [Baseline] Configuration (cont.)

Pilot	Rating	Comments
5	0	Adequate and effective for bombing when the pilot is experienced.
	-	In the IMPACT cockpit, you look outside for the target. In the "F-15E" [Baseline], you have to look inside to get SA.
6	0	It is a two person job. No sane person would do it single-seat.
	0	One of the hard things is not knowing altitude. You can get azimuth off the TEWS, but spend time figuring altitude.
	-	Inbound in pop, you had to think about where the target would be since you had no cues.
8	0	TA was improved compared to F-111E and was poor compared to IMPACT. Night pop - OK.
	-	IMPACT cockpit display and the HMD is significantly better than the "F-15E" [Baseline] cockpit, better with HMD.
	-	"F-15E" [Baseline] HUD needs algebraic signs to show dive.
	-	Controlling the A/C takes a significant amount of time while trying to find threats.
9	-	The "F-15E" [Baseline] TEWS gives you azimuth, but does not help with threat elevation.
	+	Overall excellent.
	+	Would like a TSD in the F-16.
10	0	It is acceptable, but needs to be tweaked. The HUD symbology for altitude (above and below horizon) needs to be changed.
	-	I do not like "F-15E" [Baseline] HUD. There is no perception of up and down on HUD.
11	-	Only source of azimuth was TEWS. No source of evaluation. Really missed bore cross and target locator like from F-16.
	-	Limited capability if you are careful - accident waiting to happen if tapped - threat detect/react alone justifies HMD.
	-	Not having symbology makes threats much more difficult to acquire. Must look at TEWS, roll, look.
	0	Vectored aspect is where I miss HMD most.
12	-	Unsuitable without audio warnings.

Pilots' Verbal Comments Regarding the "F-15E" [Baseline] Configuration (cont.)

Pilot	Rating	Comments
13	+	The TSD is very good. The HMD "gray dot" is totally unacceptable to me.
	-	Overall cockpit is fine. I do not like the HMD "gray dot." I do not like the HUD Attitude indicator. It does not depict the difference between the "air" and "ground" very well.
14	0	Acceptable.
15	0	Threat acquisition cockpit display OK, but still hard to acquire threat at night. Night pop-up is difficult, but not impossible.
	0	FLIR glare made threat #1 hard to see. Threats are easier to see if you don't have to maneuver the A/C.
	-	In the "F-15E" [Baseline] it takes at least 1 to 1 1/2 seconds more to find threats than in the IMPACT cockpit.
	-	HUD declutter mode to erase some HUD symbology would be nice.
16	+	Great cockpit- helped in many ways; did not help find target once in pull-up.
17	-	Engine instruments should be higher.
18	0	I am not sure that either setup is right, but IMPACT is moving in the right direction.

Pilots' Written Comments on the HMD

Pilot	Rating	Comments
2	+	Great aid in threat and target acquisition. I found that I performed much better toward the end as I learned how best to use the HMD. I felt high on the learning curve for threat acquisition, but I had only just begun to use the HMD effectively in bombing.
4	+	Determination of threat location is the single most valuable capability of the HMD. Another, which was not tested, would be determination of wingman location. These capabilities would be used so often that using the HMD would become second nature.
5	-	I found that the transition from the HMD to the HUD for acquiring the target slightly degraded my ability to bomb. There was slight "confusion" until the target was completely in the HUD.
9	+	This by far was the most effective way to find the threat.
11	+	Wow - however, the threat locator line needs to be dashed to deconflict with horizon line. What is the plan for multiple threats? I see a potential mess.
13	0	I am not comfortable with this technology yet. I do like the threat locator technology with the IMPACT cockpit. General Comment: Overall I did not use the HMD for "anything forward." I only used it to locate targets outside the front field of view. I relied on the head down or HUD information for airspeed, heading, and attitude. I think I would need more familiarity/training with the HMD to gain more confidence with its use.
14	-	As I started to turn the aircraft to detect threats near 6 o'clock, I found the threat locator line somewhat confusing. If I got a majority of the turn out of the way and used the TSD along with the HMD, I did fine. However, just using the HMD alone for detecting threats in the rear hemisphere was confusing.
15	+	The HMD was excellent in determining threat elevation.
18	0	Might consider blanking the HUD when the FOVs overlap. Put everything on the HMD (e.g., FLIR display, pitch ladder when looking forward only).

Pilots' Written Comments on the TSD

Pilot	Rating	Comments
4	0	Might help to make current steerpoint a recognizable/different cue. I went backwards several times.
7	+	Best SA device ever. Should be combined with moving map.
9	+	The TSD was better at telling you that you are being targeted by a threat than your wingman would be. The threat label was also useful.
11	+	Specifically, I liked the large TSD, especially compared to the F-16 Block 50D horizontal situation display (monochromatic, small).
13	+	Is essential for SA. I rely on the TSD when it is available.
14	0	Very good for SA. However, the colors selected could be better and more targeting information could be added. Additionally, a radar display and a hands on throttle and stick (HOTAS) capability to adjust the display would be useful.
15	0	Nice display, but too much "heads down."

Pilots' Written Comments on Directional Audio

Pilot	Rating	Comments
5	+	Very effective.
6	+	Never noticed the directional audio inflight. Too many other aural cues were happening to notice it, except maybe subconsciously.
7	+	True 3-D audio would be fantastic.
12	+	Critical technology for SA and effective control in complex audio environment.
15	+	Great source of info for initial target direction.
18	0	I never consciously used it, but I do not know if I turned my head to the right place unconsciously.

Pilots' Comments on the HMD Elements

Pilot	Rating	**Threat Cueing Symbol Comments:**
1	-	I think the cueing symbol (line) is too long. Move the chevrons closer to the aiming cross.
4	-	It is probably too small. The real sensor accuracy will not be as good as the simulation. Small cue leads to belief that you will find threat in that small zone. Could lead to missing threat due to focused search. Also, too bright for simulation.
6	-	Sometimes easy to confuse with horizon line for 6 o'clock threats.
12	-	Threat line needs to have an urgency-cueing capability. (Strobes for more dangerous (closer) threats).
14	-	The HMD display could have better resolution and fit. The general idea was good, but actual implementation could be better.
15	+	OK.
Pilot	Rating	**Target/Waypoint Symbol Comments:**
4	0	Keep it common with HUD.
5	0	Make sure the waypoints go under the plane. They should be fixed to the ground.
11	0	Need to be consistent - ordinary waypoints 0. See picture.
15	0	Show 3-D.
Pilot	Rating	**Master Arm Indication:**
2	-	Too small to read.
4	-	Why have it? It is more clutter.
7	0	Never saw it.
14	-	Could not read it clearly.
Pilot	Rating	**Airspeed Indication:**
2	-	Too small to read.
4	0	Stay common with the HUD.
5	0	Both were slightly harder to read.
9	0	Need an analog and digital airspeed indicator. Also, need to have a speed caret for guidance on programmed speed.
10	-	OK, but it would be better to have a tape display.
11	-	Delete it.
15	-	Make it bigger.
17	-	Fuzzy small, unreadable; analog display would be better. Have capability to bug a desired speed, and show how fast or slow you are to the reference.
Pilot	Rating	**Orange Peel:**
2	0	It's not intuitive. I never used it.
4	-	If I tried to use it while looking back, it caused channelized attention.
5	0	Try to get a couple unusual attitude situations to see how the indicator operates.
7	-	Lose the orange peel.
9	0	Never used it. It might be a little small.
10	0	Did not even notice it.
11	-	Too small to be useable.
12	-	Need different mechanization - it is confusing and unreadable.

Pilots' Comments on the HMD Elements (cont.)

13	-	I do not like the "orange peel" attitude system, but if we must have one I would like it to be bigger.
14	-	Size and location made it difficult to use. I used HUD instead.
15	-	Too small.
Pilot	Rating	**Horizon Line:**
4	-	Needs to have a different texture/look than the threat cue line (I became confused when threat was near horizon).
13	-	I think it would be better to make the horizon line easily distinguishable from the threat cueing line. Perhaps you could also add some slash marks in a downward direction to depict the ground.
15	-	Change it: maybe.
18	-	Delete it. It is confusing with other solid lines. If you cannot delete it, make it different.
Pilot	Rating	**Aiming Cross:**
4	+	I like it. It seems to give a common reference that keeps all the HMD symbology in perspective.
10	-	There is too much trash. I prefer a simple aiming cross.
Pilot	Rating	**Mach Indication:**
4	0	Stay common with the HUD.
5	-	Both were slightly hard to read.
7	-	Do not need it in the HMD.
11	-	Delete it.
14	-	Could not read clearly.
15	-	Delete it.
17	-	Fuzzy small, unreadable; analog display would be better. Have capability to bug a desired speed, and show how fast or slow you are to the reference.
Pilot	Rating	**Radar Altitude:**
5	-	It was too far from the center of vision to be used effectively.
11	-	I did not use it. Make sure it is declutterable.
15	-	Too small. Only one (radar or baro altitude) is required. Use baro above 3000 feet AGL.
Pilot	Rating	**Baro Altitude:**
11	-	Delete it.
15	-	Too small. Only one (radar or baro altitude) is required. Use baro above 3000 feet AGL.

Pilots' Comments on the TSD Elements

Pilot	Rating	**SAM Threat Symbol:**
1	-	The hexagon symbol with the missile flying out became slightly confusing. (Is it a SAM or an aircraft?) Perhaps we should delete the missile inflight and leave the hexagon.
4	-	If the location data (e.g., range/bearing) are reasonably accurate, then it is good. Otherwise, it could be (fatally) misleading.
7	-	Need better indication of lock-on to discriminate between SAMs and air-to-air threats.
9	+	Great. It adds SA.
15	+	It is OK.
Pilot	Rating	**Air-to-Air Threat Symbol:**
4	+	If the location data (e.g., range/bearing) are reasonably accurate, then it is good. Otherwise, it could be (fatally) misleading.
5	0	It might be helpful to have speed and "bad guy" symbology on the HMD. It wasn't until after I acquired the "bogie" did I come back inside.
7	-	Need better indication of lock-on to discriminate between SAMs and air-to-air threats.
9	+	Great. It adds SA.
15	+	It is OK.
Pilot	Rating	**Waypoint Symbol:**
9	+	Great. It adds SA.
15	0	Add information such as time and fuel at waypoint.
Pilot	Rating	**Aircraft Symbol:**
9	+	Great. It adds SA.
15	+	It is OK.
Pilot	Rating	**Course Line:**
9	+	Great. It adds SA.
15	+	It is OK.

APPENDIX F

STATISTICAL DATA

STATISTICAL DATA

1. Measures of Effectiveness

The measures of effectiveness that were addressed in this experiment include threat acquisition time and threat acquisition success rate.

1.1 Threat Acquisition Time

A 2 x 2 x 3 (Cockpit Configuration by Threat Difficulty by Mission Phase) repeated measures ANOVA was performed on the threat acquisition time data. A significant Cockpit Configuration by Threat Difficulty interaction was found, $F(1,17) = 8.20$, $p < .05$. A simple main effect analysis indicated that threat acquisition time was significantly shorter for the IMPACT cockpit versus the baseline in the easy threat condition, $F(1,17) = 56.73$, $p < .05$, as well as the hard threat condition, $F(1,17) = 52.63$, $p < .05$. The interaction was caused by the magnitude of delta between Cockpit Configuration as a function of Threat Difficulty (see Figure 1).

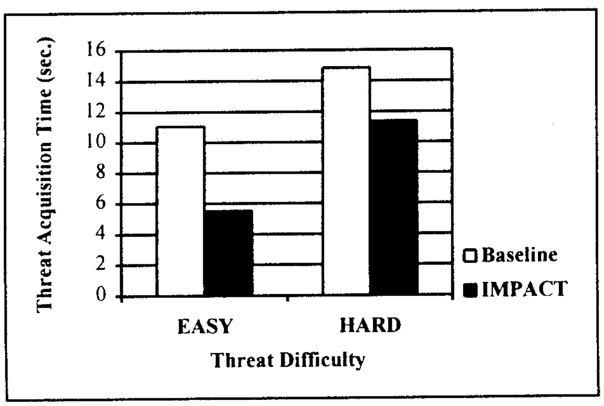

Figure 1. Mean Threat Acquisition Time

A significant Threat Difficulty by Mission Phase interaction was also found for threat acquisition time, $F(2,34) = 15.59$, $p < .05$. A simple main effect analysis indicated that threat acquisition time was significantly shorter for easy threats versus hard threats for Medium Altitude Cruise, $F(1,17) = 17.20$, $p < .05$, TFR Descent, $F(1,17) = 14.41$, $p < .05$, and TFR Ingress, $F(1,17) = 81.47$, $p < .05$. The interaction was caused by the magnitude of delta between

Threat Difficulty as a function of the Mission Phase. No other interactions were discovered for threat acquisition time.

A significant main effect for Cockpit Configuration was found as a function of threat acquisition time, $F(1,17) = 80.65$, $p < .05$. Threat acquisition time was significantly shorter with the IMPACT cockpit (M RMS = 8.43 sec.) versus the baseline (M RMS = 12.95 sec.).

A significant main effect for Threat Difficulty was found as a function of threat acquisition time, $F(1,17) = 75.46$, $p < .05$. Threat acquisition was significantly shorter with the easy threats (RMS M = 8.28 sec.) versus hard threats (M RMS = 13.10 sec.).

A significant main effect for Mission Phase was found as a function of threat acquisition time, $F(1,17) = 9.84$, $p < .05$. It appears that threat acquisition time was longer during the Medium Altitude Cruise Phase (M RMS = 12.15 sec.) versus the TFR Descent (M RMS = 10.52 sec.) or the TFR Ingress (M RMS = 10.04 sec.). No other main effects were discovered. See Table 1 for a summary of threat acquisition time results, in which the statistically significant p-values are in bold type.

Table 1. Threat Acquisition Time Results

Source	**F**	**Significance**
Configuration	$F(1,17) = 80.65$	**$p < .05$**
Threat Difficulty	$F(1,17) = 75.46$	**$p < .05$**
Phase	$F(2,34) = 9.84$	**$p < .05$**
Configuration by Threat Difficulty	$F(1,17) = 8.20$	**$p < .05$**
Configuration by Phase	$F(2,34) = 1.18$	$p > .05$
Threat Difficulty by Phase	$F(2,34) = 15.59$	**$p < .05$**
Configuration by Threat Difficulty by Phase	$F(2,34) = 0.20$	$p > .05$

1.2 Threat Acquisition Success Rate

A 2 x 2 x 3 (Cockpit Configuration by Threat Difficulty by Mission Phase) repeated measures ANOVA was performed on the threat acquisition success rate data. A significant main

effect was found for Cockpit Configuration, $F(1,17) = 32.89$, $p < .05$. As shown in Figure 2, approximately 20% more threats were acquired with the IMPACT cockpit than with the baseline throughout the entire mission.

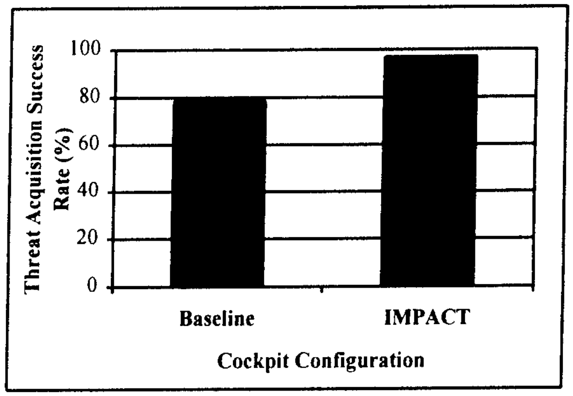

Figure 2. Mean Threat Acquisition Success Rate

A significant Threat Difficulty by Mission Phase interaction was discovered, $F(2,34) = 7.34$, $p < .05$. A simple main effect analysis indicated that success rate was significantly higher for easy threats versus hard threats during TFR Ingress only, $F(1,17) = 15.15$, $p < .05$. No other interactions were discovered for threat acquisition success rate.

A significant main effect for Threat Difficulty was found as a function of threat acquisition success rate, $F(1,17) = 6.85$, $p < .05$. Success rate was significantly higher for easy threats (M RMS = 91.60%) versus hard threats (M RMS = 83.91%).

A significant main effect for Mission Phase was found as a function of threat acquisition success rate, $F(1,17) = 4.86$, $p < .05$. It appears that threat acquisition success rate increased significantly from one mission phase to the next. Mean RMS for Medium Altitude Cruise = 82.26%, mean RMS for TFR Descent = 86.94%, and mean RMS for TFR Ingress = 90.90%. No other main effects were discovered. For a summary of threat acquisition success rate results, see Table 2.

Table 2. Threat Acquisition Success Rate Results

Source	F	Significance
Configuration	F(1,17) = 32.89	**p < .05**
Threat Difficulty	F(1,17) = 6.85	**p < .05**
Phase	F(2,34) = 4.86	**p < .05**
Configuration by Threat Difficulty	F(1,17) = 1.65	p > .05
Configuration by Phase	F(2,34) = 0.47	p > .05
Threat Difficulty by Phase	F(2,34) = 7.34	**p < .05**
Configuration by Threat Difficulty by Phase	F(2,34) = 2.68	p > .05

2. Measures of Workload

Workload was measured using SWAT. A 2 x 2 x 3 (Cockpit Configuration by Threat Difficulty by Mission Phase) repeated measures ANOVA was performed on the SWAT data. A significant Configuration by Threat Difficulty interaction was discovered, $F(1,17) = 5.48$, $p < .05$. A simple main effect analysis indicated that SWAT scores were significantly lower for the IMPACT cockpit versus the baseline in the easy threat condition, $F(1,17) = 58.21$, $p < .05$, as well as the hard threat condition, $F(1,17) = 12.69$, $p < .05$. The interaction appeared to be caused by the magnitude of the delta between Cockpit Configurations as a function of Threat Difficulty (see Figure 3).

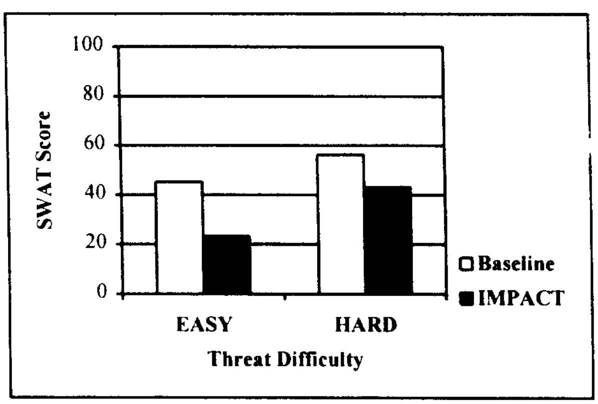

Figure 3. Mean SWAT Scores

A significant Threat Difficulty by Mission Phase interaction was also found for SWAT scores, $F(2,34) = 9.14$, $p < .05$. A simple main effect analysis indicated that SWAT scores were significantly lower for easy threats versus hard threats during Medium Altitude Cruise, $F(1,17) = 17.38$, $p < .05$, and TFR Ingress, $F(1,17) = 70.23$, $p < .05$, only. No other interactions were found for SWAT scores.

A significant main effect for Cockpit Configuration was found as a function of SWAT scores, $F(1,17) = 45.18$, $p < .05$. Scores were significantly lower for the IMPACT cockpit (M = 33.20) versus the baseline (M = 50.78).

A significant main effect for Threat Difficulty was found as a function of SWAT scores, $F(1,17) = 66.68$, $p < .05$. SWAT scores were significantly lower for easy threats (M = 34.23) versus hard threats (M = 49.75). No other main effects were found.

For the Weapon Delivery Phase, a separate 2 x 2 (Cockpit Configuration by Target Difficulty) repeated measures ANOVA was performed on the SWAT data. No significant differences were found in SWAT scores regarding Target Difficulty or Cockpit Configuration. See Table 3 for a summary of SWAT results.

Table 3. SWAT Score Results

Source	**F**	**Significance**
Configuration	$F(1,17) = 45.18$	**$p < .05$**
Threat Difficulty	$F(1,17) = 66.68$	**$p < .05$**
Phase	$F(2,34) = 2.72$	$p > .05$
Configuration by Threat Difficulty	$F(1,17) = 5.48$	**$p < .05$**
Configuration by Phase	$F(2,34) = 0.78$	$p > .05$
Threat Difficulty by Phase	$F(2,34) = 9.14$	**$p < .05$**
Configuration by Threat Difficulty by Phase	$F(2,34) = 0.71$	$p > .05$
Configuration (Weapon Delivery)	$F(1,17) = 0.12$	$p > .05$
Target Difficulty (Weapon Delivery)	$F(1,17) = 0.16$	$p > .05$
Configuration by Target Difficulty	$F(1,17) = 0.25$	$p > .05$

3. Measures of Situation Awareness

A SWORD form was given to the pilots to evaluate situation awareness for each of the following Mission Functions: threat acquisition, target acquisition, and fly/navigate. The results are shown in Figure 4.

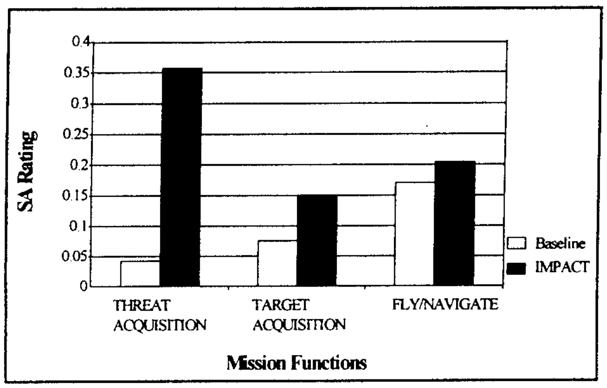

Figure 4. Mean SWORD Situation Awareness Ratings

A 2 x 3 (Cockpit Configuration by Mission Function) repeated measures ANOVA was performed on SWORD data. A significant Cockpit Configuration by Mission Function interaction was discovered, $F(2,34) = 29.98$, $p < .05$. A simple main effect analysis indicated that SA was rated relatively higher for the IMPACT cockpit during threat acquisition, $F(1,17) = 76.43$, $p < .05$, and target acquisition, $F(1,17) = 15.90$, $p < .05$, only. There was no statistically significant difference between cockpits for SA during the fly/navigate function. For a summary of SWORD results, see Table 4.

Table 4. SWORD Rating Results

Source	**F**	**Significance**
Configuration	$F(1,17) = 88.16$	**$p < .05$**
Function	$F(2,34) = 6.25$	**$p < .05$**
Configuration by Function	$F(2,34) = 29.98$	**$p < .05$**

4. Measures of Performance

The performance measures collected and analyzed in this experiment include flight performance during threat acquisition and flight performance during weapon delivery.

4.1 Flight Performance During Threat Acquisition

All flight path tracking analyses were conducted using a 2 x 2 (Cockpit Configuration by Threat Difficulty) repeated measures ANOVA. Separate analyses were conducted based on Mission Phase (Medium Altitude Cruise, TFR Descent, and TFR Ingress). Separate analyses were performed because each phase had different MOPs, as well as different altitude and airspeed criteria specified. Only the data collected during threat engagements were analyzed.

In the Medium Altitude Cruise Phase, deviations from planned altitude, course, and groundspeed were analyzed. A significant Configuration by Threat Difficulty interaction was found, $F(1,17) = 5.21$, $p < .05$. A simple main effect analysis indicated that altitude deviation was significantly lower for the IMPACT cockpit (M RMS = 107.95 ft.) versus the baseline (M RMS = 285.68 ft.) in the easy threat condition only, $F(1,17) = 6.42$, $p < .05$. No significant effects were found between the IMPACT cockpit and the baseline in the hard threat condition.

Also in the Medium Altitude Cruise Phase, a significant main effect for Cockpit Configuration as a function of course deviation was found, $F(1,17) = 43.18$, $p < .05$. Pilots maintained course significantly better with the IMPACT cockpit versus the baseline regardless of threat difficulty (see Figure 5).

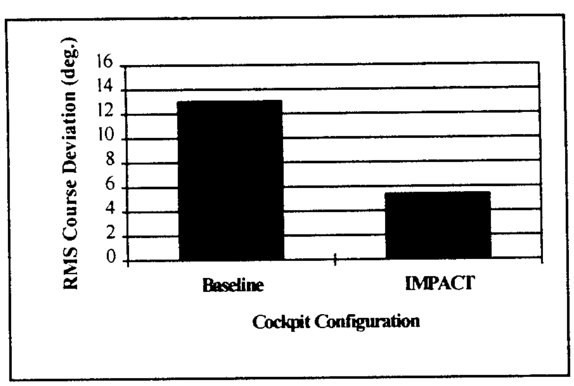

Figure 5. Mean RMS Course Deviation During Medium Altitude Cruise

For groundspeed, no significant differences were found between the IMPACT cockpit and the baseline cockpit.

Significant main effects were found for Threat Difficulty as a function of both course deviation, $F(1,17) = 5.9$, $p < .05$ and groundspeed deviation $F(1,17) = 19.7$, $p < .05$. Smaller course deviations were found in the easy threat condition (M RMS = 6.85°) than the hard threat condition (M RMS = 11.58°). Smaller groundspeed deviations were found in the easy threat condition (M RMS = 18.50 kts.) than the hard threat condition (M RMS = 49.99 kts.). No other interaction or main effects were discovered. A summary of flight performance results for the Medium Altitude Cruise Phase is provided in Table 5.

Table 5. Medium Altitude Cruise Flight Performance Results

Source	**F**	**Significance**
Configuration (Altitude Deviation)	$F(1,17) = 1.00$	$p > .05$
Configuration (Course Deviation)	$F(1,17) = 43.13$	**$p < .05$**
Configuration (Groundspeed Deviation)	$F(1,17) = 0.05$	$p > .05$
Threat Difficulty (Altitude Deviation)	$F(1,17) = 9.29$	**$p < .05$**
Threat Difficulty (Course Deviation)	$F(1,17) = 5.89$	**$p < .05$**
Threat Difficulty (Groundspeed Deviation)	$F(1,17) = 19.66$	**$p < .05$**
Configuration by Threat Difficulty (Altitude Deviation)	$F(1,17) = 5.21$	**$p < .05$**
Configuration by Threat Difficulty (Course Deviation)	$F(1,17) = 3.70$	$p > .05$
Configuration by Threat Difficulty (Groundspeed Deviation)	$F(1,17) = 2.30$	$p > .05$

Deviation from planned dive angle was analyzed in the TFR Descent Phase. No interaction effects or main effects were found.

In the TFR Ingress Phase, deviations from planned course, groundspeed, and terrain following were analyzed. Significant main effects for Cockpit Configuration were found for course deviation, $F(1,17) = 10.97$, $p < .05$, and TFR deviation, $F(1,17) = 8.19$, $p < .05$. Course deviation was significantly smaller with the IMPACT cockpit versus the baseline. Also, TFR

deviation was significantly less with the IMPACT cockpit versus baseline. No significant differences were found between cockpit configurations for groundspeed deviation. See Table 6 for mean RMS results.

Table 6. Significant Cockpit Configuration RMS Results for the TFR Ingress Phase

Variable	Baseline	IMPACT
Course Deviation	M = 4.33°	M = 3.00°
TFR Deviation	M = 23.44 mr	M = 19.04 mr

Significant main effects were found for Threat Difficulty as a function of course deviation, $F(1,17) = 71.73$, $p < .05$, groundspeed deviation, $F(1,17) = 19.34$, $p < .05$, and TFR deviation, $F(1,17) = 49.33$, $p < .05$. See Table 7 for mean RMS results. No other interaction effects or main effects were discovered. See Table 8 for a summary of flight performance results during TFR Ingress.

Table 7. Significant Threat Difficulty RMS Results for the TFR Ingress Phase

Variable	Easy Threats	Hard Threats
Course Deviation	M = 1.66°	M = 5.74°
Groundspeed Deviation	M = 15.25 kts	M = 24.55 kts
TFR Deviation	M = 16.06 Mr	M = 26.65 Mr

Table 8. TFR Ingress Flight Performance Results

Source	F	Significance
Configuration (Course Deviation)	$F(1,17) = 10.97$	**$p < .05$**
Configuration (Groundspeed Deviation)	$F(1,17) = 0.01$	$p > .05$
Configuration (TFR Deviation)	$F(1,17) = 8.19$	**$p < .05$**
Threat Difficulty (Course Deviation)	$F(1,17) = 71.73$	**$p < .05$**
Threat Difficulty (Groundspeed Deviation)	$F(1,17) = 19.34$	**$p < .05$**
Threat Difficulty (TFR Deviation)	$F(1,17) = 49.33$	**$p < .05$**
Configuration by Threat Difficulty (Course Deviation)	$F(1,17) = 0.91$	$p > .05$
Configuration by Threat Difficulty (Groundspeed Deviation)	$F(1,17) = 0.69$	$p > .05$
Configuration by Threat Difficulty (TFR Deviation)	$F(1,17) = 0.61$	$p > .05$

4.2 Flight Performance During Weapon Delivery

A weapon delivery analysis was conducted using a 2 x 2 (Cockpit Configuration by Target Difficulty) repeated measures ANOVA. Deviations from planned vertical flight, attack course, and groundspeed were analyzed in the Weapon Delivery Phase. A significant main effect was found for Target Difficulty for vertical flight deviation only, $F(1,17) = 7.97$, $p < .05$. In this case, pilots had significantly less vertical flight deviation with the easy target condition (M RMS = 315.42 ft.) than with the hard target condition (M RMS = 503.28 ft.). No other main effects or interactions were found for attack course deviation or groundspeed deviation. In addition, no significant differences were found between the cockpit configurations for any of the flight performance variables. See Table 9 for a summary of flight performance results during the Weapon Delivery Phase.

Table 9. Weapon Delivery Flight Performance Results

Source	F	Significance
Configuration (Vertical Flight Deviation)	$F(1,17) = 1.74$	$p > .05$
Configuration (Course Deviation)	$F(1,17) = 0.93$	$p > .05$
Configuration (Groundspeed Deviation)	$F(1,17) = 0.16$	$p > .05$
Target Difficulty (Vertical Flight Deviation)	$F(1,17) = 7.97$	**$p < .05$**
Target Difficulty (Course Deviation)	$F(1,17) = 1.93$	$p > .05$
Target Difficulty (Groundspeed Deviation)	$F(1,17) = 2.69$	$p > .05$
Configuration by Target Difficulty (Vertical Flight Deviation)	$F(1,17) = 0.00$	$p > .05$
Configuration by Target Difficulty (Course Deviation)	$F(1,17) = 0.02$	$p > .05$
Configuration by Target Difficulty (Groundspeed Deviation)	$F(1,17) = 0.09$	$p > .05$

5. Subjective Data

Frequencies and mean ratings were calculated for all questionnaire items employing rating scales. Complete responses to open-ended questions and other pilot comments collected are included in Appendix E. Both post-mission and post-experiment questionnaires were used to address the overall contributions as well as the specific individual contributions of each advanced technology element.

5.1 Threat Acquisition Effectiveness

The pilots were asked for their assessment of the two cockpits in threat acquisition. Figure 6 illustrates the difficulty ratings given for threat acquisition with respect to cockpit configuration. Threat acquisition in the IMPACT cockpit was rated easier than in the baseline cockpit by the pilots.

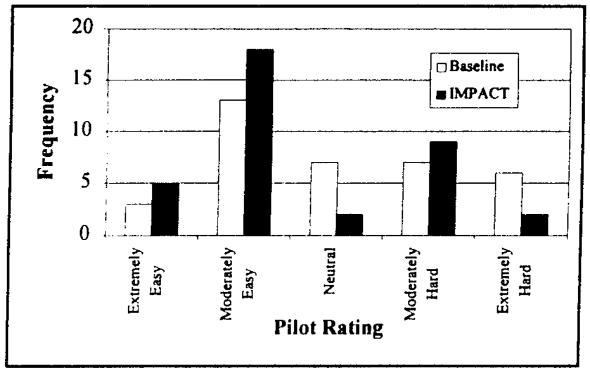

Figure 6. Post-Mission Pilot Difficulty Ratings for Threat Acquisition

For threat acquisition, 16 out of 18 pilots specifically commented that IMPACT was a vast improvement over the baseline. This was predominantly due to the HMD threat cueing capability. Conversely, six out of 18 pilots specifically commented that threat acquisition in the baseline was more difficult, mainly because of the lack of threat elevation cueing.

Threat acquisition was broken into three elements: determination of azimuth, determination of elevation, and determination of range. Figure 7 depicts the overall cockpit effective for these tasks.

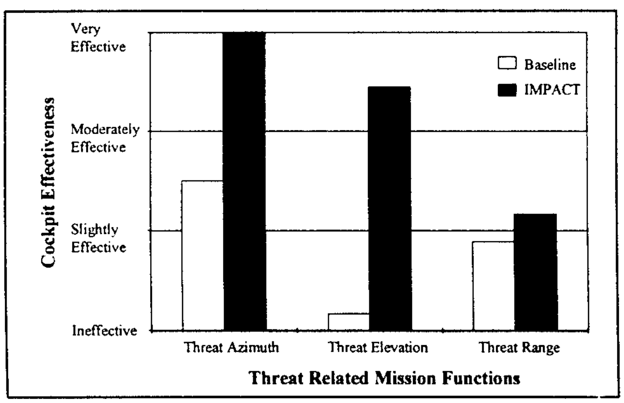

Figure 7. Average Cockpit Effectiveness Ratings for Determining Threat Location

The pilots were then asked to give their assessment of the contribution of each of the technologies to the threat acquisition elements. Figure 8 depicts their responses.

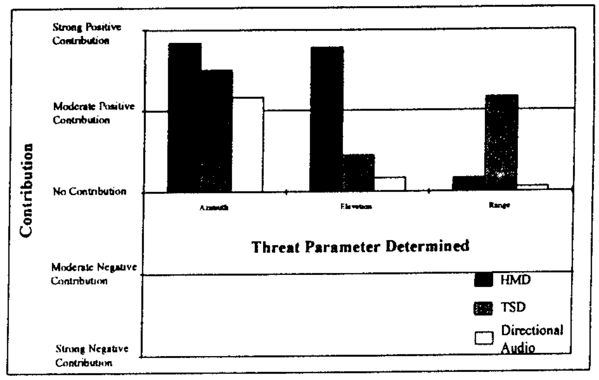

Figure 8. Contributions of Technologies to Threat Localization

The HMD was rated by the pilots as making its strongest contribution in determining azimuth and elevation. The TSD made its largest contributions in threat azimuth and range and the directional audio made a moderate contribution in azimuth only.

Thirteen out of 18 pilots specifically commented that the HMD improved threat acquisition. Figures 9 and 10 illustrate the specific contribution made by the HMD threat cueing symbology in determining threat azimuth and elevation, respectively. In addition, the ratings indicate that additional symbology, not necessarily related to threat acquisition, did not have a degrading effect. However, six pilots did comment regarding an occasional conflict between the HMD horizon line and the HMD threat locator line. If the threat was at the same altitude as the aircraft, both lines would overlap in the HMD. The only symbology that then remained to indicate the threat location was two chevrons displayed at the outer edge of the HMD FOV.

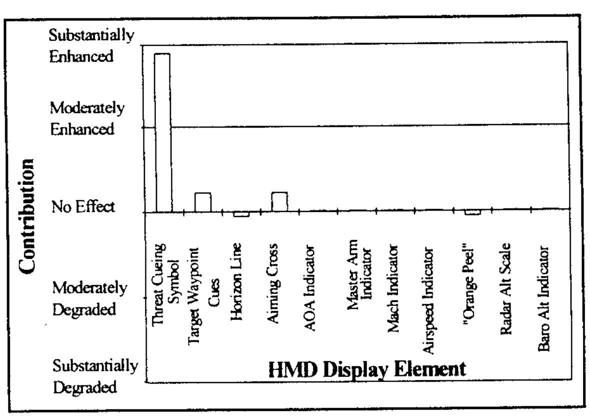

Figure 9. Contributions of HMD Elements to Determining Threat Azimuth

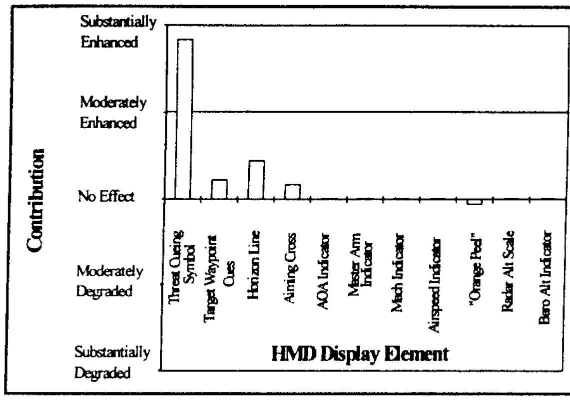

Figure 10. Contributions of HMD Elements to Determining Threat Elevation

As mentioned previously, the TSD was assessed favorably in the determination of threat azimuth and range. The positive rating was most likely due to the pilots' ability to scan a large scale presentation of the threat location. None of the pilots had negative comments concerning the TSD, however the following changes were suggested:

- Provide a differentiable symbol separating the current steerpoint from past or future steerpoints
- Combine the display with a moving map
- Provide more targeting information

Figures 11, 12, and 13 illustrate the specific contributions of TSD symbology in determining threat azimuth, elevation, and range. Of the three tasks required to acquire a threat, determination of elevation using the TSD was given the lowest ratings (See Figure 12).

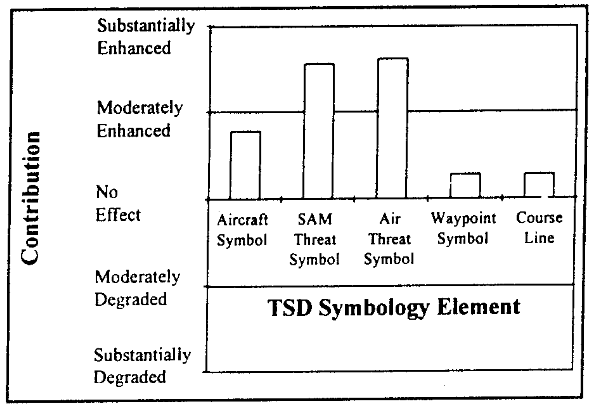

Figure 11. Contributions of TSD Elements to Determining Threat Azimuth

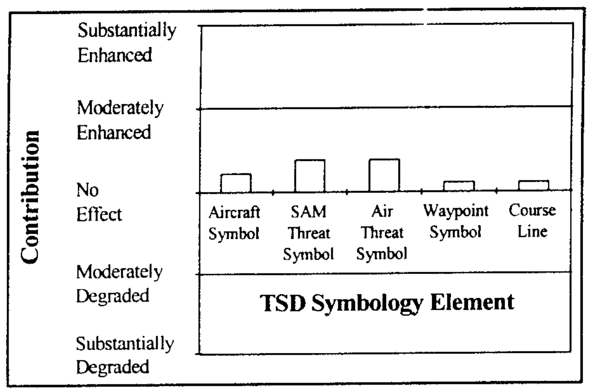

Figure 12. Contributions of TSD Elements to Determining Threat Elevation

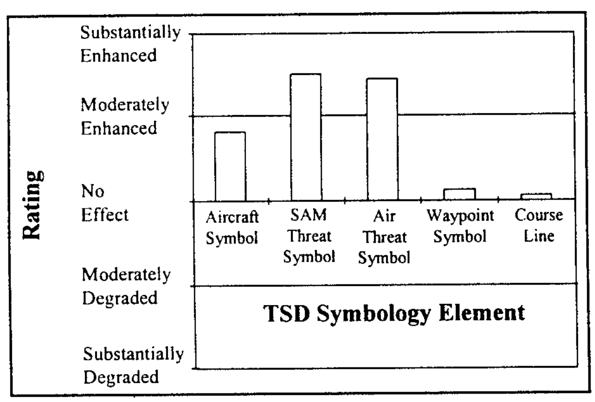

Figure 13. Contributions of TSD Elements to Determining Threat Range

Finally, directional audio was rated the lowest of the three advanced technologies for threat acquisition. This was probably because of the limited capability of the audio system (azimuth only), as well as the lack of pilot experience with advanced audio capabilities. Of the three technologies, directional audio seemed to be the most foreign to the pilots as indicated by their

wide range of comments. Five pilots indicated that the directional audio was helpful in determining initial head movements. However, three pilots commented that they were not always consciously aware of the audio cueing and would require more training before using it.

5.2 Weapon Delivery Effectiveness

Figure 14 illustrates the post-mission subjective ratings given by the subjects with respect to configuration and target acquisition difficulty.

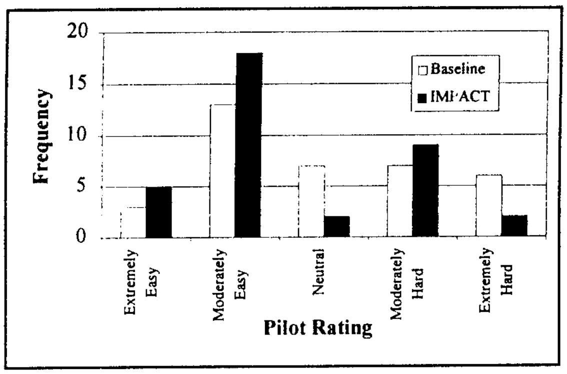

Figure 14. Post-Mission Difficulty Ratings for Target Acquisition

Target acquisition was rated slightly easier in the IMPACT cockpit than in the baseline cockpit. The following pilot comment provides a possible reason for the rating: "I used (the) helmet to see when to roll out . . . (I) had more time than would have had otherwise."

Figure 15 depicts cockpit effectiveness ratings for the target acquisition and weapon delivery functions. Again, the IMPACT cockpit was rated higher than the baseline cockpit in both areas.

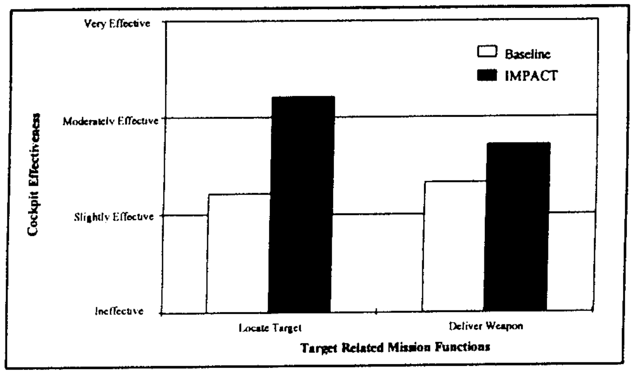

Figure 15. Average Cockpit Effectiveness Ratings for Target Acquisition and Weapon Delivery

As expected, the pilots felt the HMD and TSD were the two technologies making the largest contributions to the weapon delivery (directional audio was not used for weapon delivery). However, pilot comments were mixed. Six pilots commented that the HMD was useful in acquiring the target earlier in the engagement, thereby allowing more time for planning the attack. Four pilots commented that the transition from the HMD to the HUD was difficult and confusing. Figure 16 shows that the Target/Waypoint Cue in the HMD made a slightly positive contribution to weapon delivery.

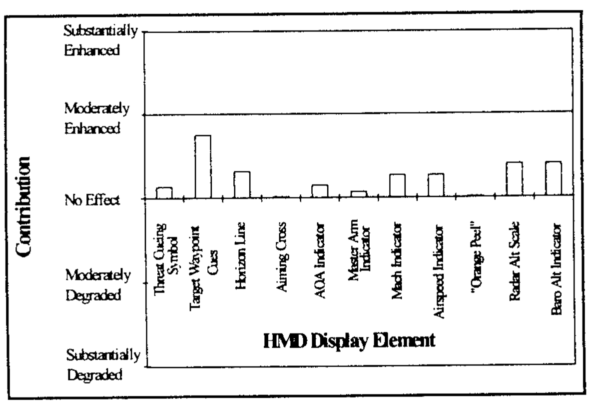

Figure 16. Contributions of HMD Elements to Weapon Delivery

Because the weapon delivery was predominantly a visual task, it was understandable that the TSD was rated slightly lower in its contribution (see Figure 17).

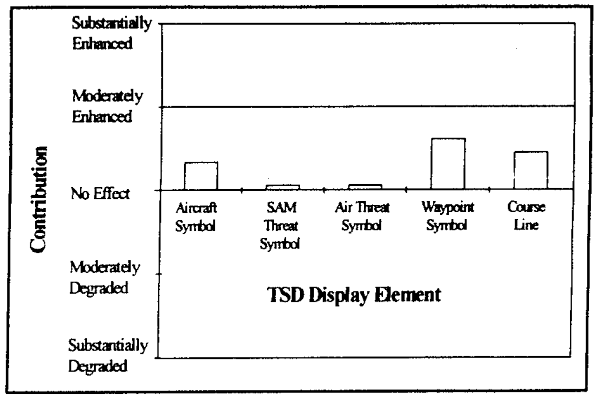

Figure 17. Contributions of TSD Elements to Weapon Delivery

5.3 Aircraft Control

Pilots were asked to assess the cockpits for flying difficulty. Figure 18 shows that they found both cockpits moderately easy to fly with IMPACT being slightly easier.

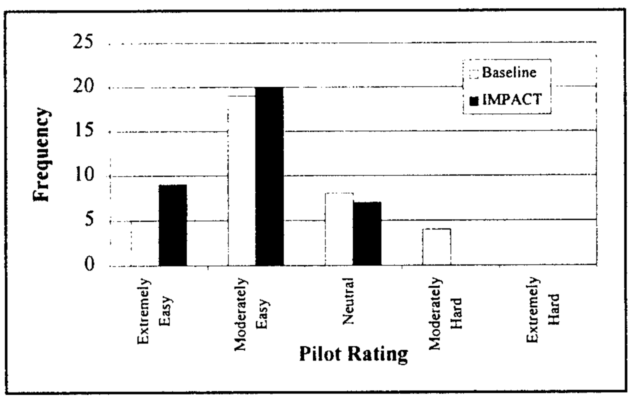

Figure 18. Post-Mission Difficulty Ratings for the Flying Function

Figure 19 shows similar results when the pilots were asked for their cockpit effectiveness ratings on the post-experiment questionnaire. IMPACT was rated slightly more effective.

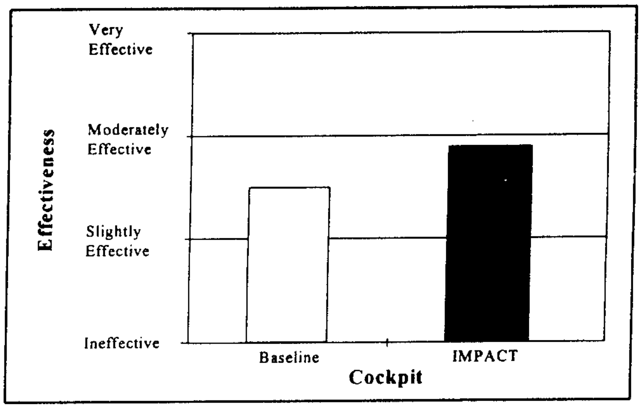

Figure 19. Average Effectiveness Ratings by Cockpit for the Flying Function

Several elements of the HMD were identified as providing small enhancements to flying. The elements are shown in Figure 20. Note that not one element was rated above "Moderately Enhanced."

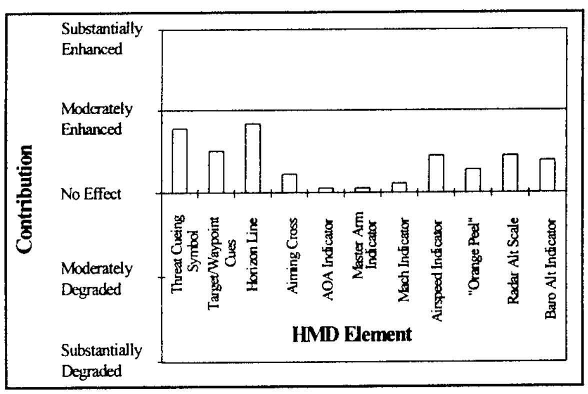

Figure 20. Average Ratings of HMD Display Elements for the Flying Function

Several of the elements of the TSD were also identified as providing small enhancements to flying and are shown in Figure 21.

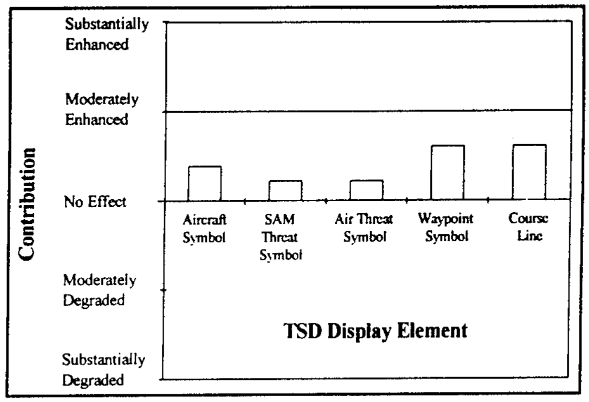

Figure 21. Average Ratings of TSD Elements for the Flying Function

Note that the only head down navigation references in the cockpit (Waypoint Symbol and Course Line) were rated as having almost no effect on flying.

The rated contributions of the three technologies toward situation awareness are shown in Figure 22 with the TSD making the largest contribution. Six out of 18 pilots specifically identified the IMPACT TSD as providing the greatest level of situation awareness.

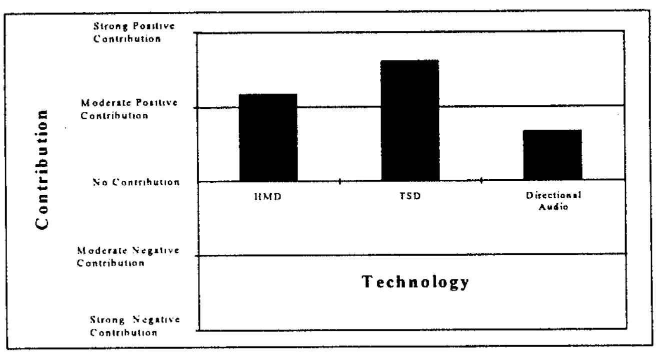

Figure 22. Contributions of Technologies to Maintaining Situation Awareness

5.4 Hardware and Design Characteristics

The design characteristics of the three technologies were examined to determine the pilots' acceptance. Figure 23 shows these acceptability ratings. The TSD was the closest to being rated completely acceptable.

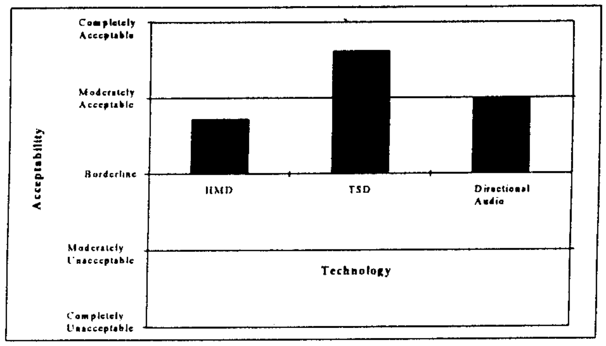

Figure 23. Average Acceptability Ratings of Design Characteristics

The following charts show the acceptability ratings for the design of the individual technologies. As shown in Figure 24, the comfort of the helmet received low ratings. The low ratings were not surprising because the helmet was a prototype required to fit multiple subjects under test conditions. Furthermore, all aspects of the HMD were difficult to setup, and it was a challenge for the experimenters to control extraneous effects in a reliable fashion.

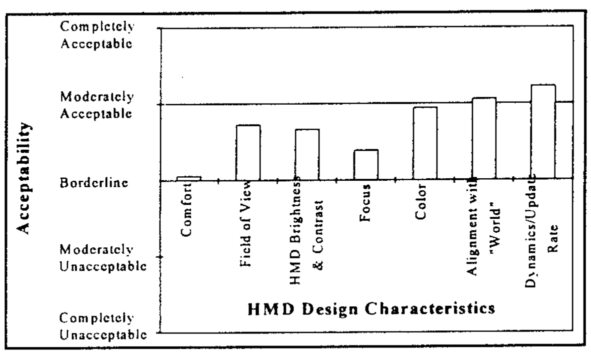

Figure 24. Average Acceptability Ratings of the HMD Design Characteristics

All the TSD design characteristics were rated almost completely acceptable (see Figure 25).

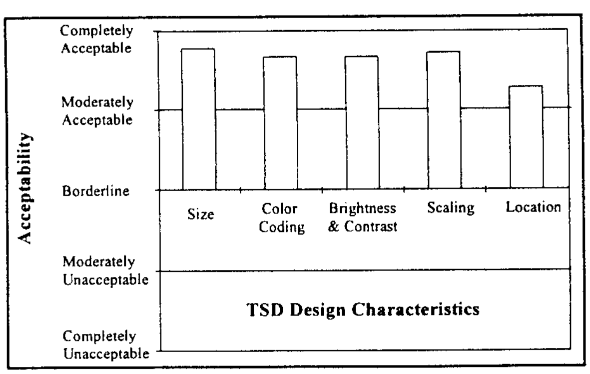

Figure 25. Average Acceptability Ratings of the TSD Design Characteristics

Finally, Figure 26 shows that the pilots gave a "Moderately Acceptable" rating for the directional audio.

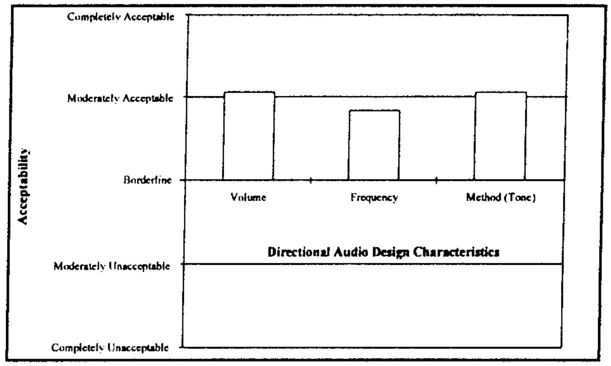

Figure 26. Average Acceptability Rating of the Directional Audio Design Characteristics